January 19, 2015

Mr. James Johnson
On-Scene Coordinator
U.S. Environmental Protection Agency, Region 7
11201 Renner Boulevard
Lenexa, Kansas 66219

Subject: **Interim Data Summary of Radiological Parameters Analyzed During Ongoing Baseline Off-Site Air Monitoring**
West Lake Landfill Site, Bridgeton, Missouri
CERCLIS ID: MOD079900932
EPA Region 7, START 4, Contract No. EP-S7-13-06, Task Order No. 0058
Task Monitor: James Johnson, On-Scene Coordinator

Dear Mr. Johnson:

Tetra Tech, Inc. is submitting the attached Interim Data Summary Report regarding radiological parameters assessed during ongoing air monitoring at locations off site of the West Lake Landfill site (WLLS) in Bridgeton, Missouri. This monitoring is occurring during a baseline period prior to start of construction of an isolation barrier at WLLS. If you have any questions or comments, please contact me at (816) 412-1775.

Sincerely,

Robert Monnig, PE
START Project Manager

Ted Faile, PG, CHMM
START Program Manager

Enclosures

cc: Debra Dorsey, START Project Officer (cover letter only)

X9025.14.0058.000

INTERIM DATA SUMMARY OF ONGOING BASELINE OFF-SITE AIR MONITORING RADIOLOGICAL PARAMETERS

WEST LAKE LANDFILL SITE
BRIDGETON, MISSOURI
CERCLIS ID: MOD079900932

Superfund Technical Assessment and Response Team (START) 4
Contract No. EP-S7-13-06, Task Order No. 0058

Prepared For:

U.S. Environmental Protection Agency
Region 7
Superfund Division
11201 Renner Blvd.
Lenexa, Kansas 66219

January 19, 2015

Prepared By:

Tetra Tech, Inc.
415 Oak Street
Kansas City, Missouri 64106
(816) 412-1741

CONTENTS

CONTENTS (Continued)

APPENDICES

TABLES

CONTENTS (Continued)

EXHIBITS

EXECUTIVE SUMMARY

The Tetra Tech, Inc. (Tetra Tech) Superfund Technical Assessment and Response Team (START) is assisting the U.S. Environmental Protection Agency (EPA) with baseline monitoring at off-site locations around the West Lake Landfill site (WLLS) in Bridgeton, Missouri, during a pre-construction, baseline period prior to initiation of construction of a planned isolation barrier at WLLS. This air monitoring will provide data for use to (1) evaluate pre-construction concentrations of chemical and radiological parameters of potential concern in outdoor air, and (2) optimize the sampling and monitoring plan for off-site air monitoring to occur during construction of the isolation barrier. During barrier construction, air monitoring will occur to address concerns that construction operations at WLLS could impact human health and the environment via release to ambient air of solid waste landfill gases of concern or of particulates with radiologically-impacted materials (RIM). This interim report summarizes data sets of radiological parameters acquired from the start of monitoring to September-December 2014.

West Lake Landfill is an approximately 200-acre property that includes several closed solid waste landfill units that accepted wastes for landfilling from the 1940s or 1950s through 2004, plus a solid waste transfer station, a concrete plant, and an asphalt batch plant. The WLLS is at 13570 St. Charles Rock Road in Bridgeton, St. Louis County, Missouri, approximately 1 mile north of the intersection of Interstate 70 and Interstate 270. The WLLS was used for limestone quarrying and crushing operations from 1939 through 1988. Beginning in the late 1940s or early 1950s, portions of the quarried areas and adjacent areas were used for landfilling municipal refuse, industrial solid wastes, and construction/demolition debris. In 1973, approximately 8,700 tons of leached barium sulfate residues (a remnant from the Manhattan Engineer District/Atomic Energy Commission project) were reportedly mixed with approximately 39,000 tons of soil from the 9200 Latty Avenue site in Hazelwood, Missouri, transported to the WLLS, and used as daily or intermediate cover material. In December 2004, the Bridgeton Sanitary Landfill—the last landfill unit at WLLS to receive solid waste—stopped receiving waste pursuant to an agreement with the City of St. Louis to reduce potential for birds to interfere with Lambert Field International Airport operations. In December 2010, Bridgeton Landfill detected changes—elevated temperatures and elevated carbon monoxide levels—in its landfill gas extraction system in use at the South Quarry of the Bridgeton Sanitary Landfill portion of the WLLS (a landfill portion not associated with known RIM). Further investigation indicated that the South Quarry Pit landfill was undergoing an exothermic subsurface smoldering event (SSE). In 2013, potentially responsible parties committed to constructing an isolation barrier that would separate the landfill portion undergoing the SSE from the RIM-containing area (EPA 2014).

WLLFOIA4312 - 004 - 0090602

EPA and START began setup of five off-site monitoring stations in April 2014 with monitoring and sampling devices (including particulate air samplers, RAE Systems AreaRAEs, Saphymo GammaTRACERs, electret ion chamber radon detectors, and optically stimulated luminescent dosimeters) and a wireless remote monitoring network. Since April/May 2014, ongoing baseline period off-site air monitoring and sampling have occurred at the following monitoring stations according to the approved quality assurance project plan (QAPP) (Tetra Tech 2014a):

Station 1 – Robertson Fire Protection District Station 2, 3820 Taussig Rd., Bridgeton, Missouri

Station 2 – Pattonville Fire Department District, 13900 St Charles Rock Rd., Bridgeton, Missouri

Station 3 – Pattonville Fire Department District Station 2, 3365 McKelvey Rd., Bridgeton, Missouri

Station 4 – Spanish Village Park, 12827 Spanish Village Dr., Bridgeton, Missouri

Station 5 – St. Charles Fire Department Station #2, 1550 S. Main St., St. Charles, Missouri.

The Station 1 through 4 locations were selected primarily for their proximate positions around WLLS (these stations are approximately 0.3 to 1 mile from WLLS, in various directions from WLLS). Station 5, designated as a reference (or background) station, is farther away from WLLS than the other stations, but still within the general vicinity so as to be representative of the North St. Louis County and eastern St. Charles County area.

The radiation air monitoring is measuring three forms of ionizing radiation (alpha, beta and gamma) by specific exposure pathways (dust/particulate, radon, and ambient gamma exposure). The monitoring includes weekly laboratory analysis of particulate filters, weekly radon monitoring with electrets, monthly deployments of environmental dosimeters for gamma exposure, and continuous gamma exposure rate monitoring. This interim report summarizes the radiation air monitoring and sampling results from the start of monitoring to September-December 2014. Overall, the radiation air monitoring and sampling results appear typical of an outdoor environment. The following are specific interim observations regarding the radiological parameters being measured at the five air monitoring stations off site of WLLS:

<u>Radionuclides on Airborne Particulates</u>

Airborne particulates are collected onto glass fiber filter media by use of high-volume air samplers. The air filters are submitted for laboratory analyses for gross alpha, gross beta, gamma-emitting radionuclides, isotopic uranium, isotopic thorium, and total alpha-emitting radium. The air filter results evaluated in this interim report are gross alpha/beta, uranium-238 (^{238}U), ^{230}Th, and total alpha-emitting radium (including ^{226}Ra). The medians and distributions of these parameters appear to be similar among the five monitoring stations. Two statistics tests—the Kruskal-Wallis and Friedman tests—were used to test for differences

WLLFOIA4312 - 004 - 0090603

in concentrations of gross alpha/beta, ^{238}U, ^{230}Th, and total alpha-emitting radium (including ^{226}Ra) among the five monitoring stations. The Kruskal-Wallis test did not identify significant differences in the mean/median characteristics among the five monitoring stations for the data examined, and the Friedman test found no indication that one station had yielded larger or smaller measurements than any other station.

Radon

Radon (^{222}Rn) has been identified as a radiological parameter of interest because it is a decay product of ^{226}Ra, a radionuclide of concern at the WLLS. Radon is also generated by decay of ^{226}Ra naturally occurring in soil and rock, and a significant portion of this radon is naturally released from the ground into the atmosphere because, as a noble gas, radon becomes unbound to soil and rock. Average weekly ^{222}Rn concentrations are measured at the five off-monitoring stations by use of electret ion chamber radon detectors (Rad Elec E-PERM®). Examination of the ^{222}Rn box plots appears to show similar median ^{222}Rn concentrations among the five monitoring stations (although results from one of two statistical tests used to evaluate the data suggest that ^{222}Rn measurements at Station 4 tend to be smaller than those at the other stations).

Exposure Rate Measurements

Hourly exposure rate measurements are obtained by use of Saphymo GammaTRACERs exposure rate monitors installed at each of the five off-site monitoring stations. Although a release of RIM via airborne particulates from the WLLS is not anticipated to yield an off-site external gamma exposure rate distinguishable from background variability, acquisition of these data are occurring for possible use as a reference for future monitoring campaigns that will include exposure rate measurements. Review of the GammaTRACER data revealed that exposure rates at the five monitoring stations fluctuated around 10 microroentgens per hour (μR/hr)—a typical exposure rate within outdoor environments (National Council on Radiation Protection and Measurements [NCRP] 1987)—with exposure rates at some stations tending slightly higher or lower than 10 μR/hr (an expected outcome due to variations in local geology and surface conditions). Notably, numerous temporary spikes in the exposure rate readings corresponded to precipitation events, indicating likely precipitation scavenging (or washout) of airborne radionuclides (a process whereby radionuclides—primarily radon daughter products—suspended as aerosols in the atmosphere coalesce with precipitation and are transported with the falling precipitation to the ground surface). Overall, the gamma rate measurements appear typical for an outdoor environment.

WLLFOIA4312 - 004 - 0090604

Environmental Dosimetry

Month-long environmental dosimetry measurements are obtained at the off-site monitoring stations by use of Landauer, Inc. InLight optically stimulated luminescent (OSL) dosimeters to supplement the exposure rate measurements obtained by use of the Saphymo GammaTRACERs. The OSL dosimetry data appear normal for outdoor ambient measurements.

WLLFOIA4312 - 004 - 0090605

1.0 INTRODUCTION

The Tetra Tech, Inc. (Tetra Tech) Superfund Technical Assessment and Response Team (START) has been tasked by the U.S. Environmental Protection Agency (EPA) to assist with baseline monitoring at off-site locations around the West Lake Landfill site (WLLS) in Bridgeton, Missouri. The monitoring effort began in April 2014 and is ongoing. This interim report summarizes data sets of radiological parameters acquired from the start of monitoring to September-December 2014.

START's tasks have included: (1) assembling and maintaining a network of off-site air monitoring stations with instrumentation and sampling devices to measure radiological and chemical parameters of concern, (2) collecting samples and coordinating laboratory analysis, (3) assisting EPA with data acquisition and management, (4) documenting the off-site air monitoring efforts, and
(5) validating/verifying initial screening of the data.

The objectives of this report are to (1) present an interim summary of the radiological data acquired, including findings related to data validation, verification, and usability; and (2) offer recommendations to optimize sampling. Tabulated data summaries and plots of the data appear within the relevant report sections. A site figure is in Appendix A. Tabulated sampling results are in Appendix B. Calculations supporting the radon measurements are in Appendix C. Results of statistical analyses are in Appendix D.

WLLFOIA4312 - 004 - 0090606

2.0 PROBLEM DEFINITION, BACKGROUND, AND SITE DESCRIPTION

EPA is conducting ongoing air monitoring at locations off site of WLLS during a pre-construction, baseline period prior to initiation of construction of a planned isolation barrier at WLLS. Air monitoring during the baseline period will provide data for use to (1) evaluate pre-construction concentrations of chemical and radiological parameters of potential concern in outdoor air, and (2) optimize the sampling and monitoring plan for the off-site air monitoring to occur during construction of the isolation barrier. During barrier construction, air monitoring will occur to address concerns that operations at WLLS could impact human health and the environment via release to ambient air of solid waste landfill gases of concern or of particulates with radiologically-impacted materials (RIM).

West Lake Landfill is an approximately 200-acre property including several closed solid waste landfill units that accepted wastes for landfilling from the 1940s or 1950s through 2004, plus a solid waste transfer station, a concrete plant, and an asphalt batch plant. The WLLS is at 13570 St. Charles Rock Road in Bridgeton, St. Louis County, Missouri, approximately 1 mile north of the intersection of Interstate 70 and Interstate 270 (see Appendix A, Figure 1). WLLS was used for limestone quarrying and crushing operations from 1939 through 1988. Beginning in the late 1940s or early 1950s, portions of the quarried areas and adjacent areas were used for landfilling municipal refuse, industrial solid wastes, and construction/demolition debris. In 1973, approximately 8,700 tons of leached barium sulfate residues (a remnant from the Manhattan Engineer District/Atomic Energy Commission project) were reportedly mixed with approximately 39,000 tons of soil from the 9200 Latty Avenue site in Hazelwood, Missouri, transported to the WLLS, and used as daily or intermediate cover material. In December 2004, the Bridgeton Sanitary Landfill—the last landfill unit at WLLS to receive solid waste—stopped receiving waste pursuant to an agreement with the City of St. Louis to reduce potential for birds to interfere with Lambert Field International Airport operations. In December 2010, Bridgeton Landfill detected changes—elevated temperatures and elevated carbon monoxide levels—in its landfill gas extraction system operating at the South Quarry of the Bridgeton Sanitary Landfill portion of the WLLS (a landfill portion not associated with known RIM). Further investigation indicated that the South Quarry Pit landfill was undergoing an exothermic subsurface smoldering event (SSE). In 2013, potentially responsible parties committed to constructing an isolation barrier that would separate the landfill portion undergoing the SSE from the RIM-containing area (EPA 2014).

3.0 SAMPLING STRATEGY AND METHODOLOGY

EPA and START began setup of the five off-site monitoring stations in April 2014; these activities included installations of electrical service, instrument weather housings, monitoring and sampling devices (including particulate air samplers, RAE Systems AreaRAEs, Saphymo GammaTRACERs, electret ion chamber radon detectors, and optically stimulated luminescent [OSL] dosimeters), and a wireless remote monitoring network. Since April/May 2014, ongoing baseline period off-site air monitoring and sampling have occurred at the following monitoring stations according the approved quality assurance project plan (QAPP) (Tetra Tech 2014a) (see Appendix A, Figure 1):

Station 1 – Robertson Fire Protection District Station 2, 3820 Taussig Rd., Bridgeton, Missouri

Station 2 – Pattonville Fire Department District, 13900 St Charles Rock Rd., Bridgeton, Missouri

Station 3 – Pattonville Fire Department District Station 2, 3365 McKelvey Rd., Bridgeton, Missouri

Station 4 – Spanish Village Park, 12827 Spanish Village Dr., Bridgeton, Missouri

Station 5 – St. Charles Fire Department Station #2, 1550 S. Main St., St. Charles, Missouri.

The Station 1 through 4 locations were selected primarily for their proximate positions around WLLS (these stations are approximately 0.3 to 1 mile from WLLS, in various directions from WLLS). Station 5 was designated as a reference (or background) station, and its location was selected according to the criterion that it be frequently upwind of WLLS and farther away from WLLS than the other stations, but still within the general vicinity so as to be representative of the North St. Louis County and eastern St. Charles County area. Station 5 is farther away from WLLS than the other stations (approximately 2.3 miles west of WLLS), frequently upwind of WLLS, roughly twice the distance from WLLS than the next closest station (Station 3), and within the general vicinity of the North St. Louis County and eastern St. Charles County area so as to be representative of that area (see wind rose presented in Appendix A, Figure 1).

The radiological parameters of potential concern were identified in the QAPP (Tetra Tech 2014a) based on historical information regarding the site and program experience with similar types of sites. During the baseline sampling period, assessment of presence of naturally occurring alpha-, beta-, and gamma-emitting radionuclides on airborne particulates is occurring. The radionuclides of potential concern based on characteristics of the West Lake RIM are thorium-230 (^{230}Th), radium-226 (^{226}Ra), and radon (^{222}Rn). Assessments of gross alpha, beta, and gamma activities (including environmental dosimetry measurements) also are occurring at each monitoring station.

WLLFOIA4312 - 004 - 0090608

Sampling is consistent with EPA methods and standard operating procedures (SOP) specified in the approved QAPP (Tetra Tech 2014a). Presented in Section 4.0 with the interim data summaries are descriptions of the project-specific sampling methods associated with the various radiological parameters assessed.

4.0 INTERIM SUMMARY AND EVALUATION OF RADIOLOGICAL DATA

The following sections present interim data summaries of the radionuclide parameters assessed during the ongoing baseline monitoring period, including time series and box plots of the data, and results of statistical analyses. Tabulated data are in Appendix B.

4.1 RADIONUCLIDES ON AIRBORNE PARTICULATES

Presence of naturally occurring alpha-, beta-, and gamma-emitting radionuclides on airborne particulates is being assessed. Based on characteristics of the West Lake Landfill RIM, the radionuclides of potential concern measurable via sampling and analyzing airborne particulates are uranium-238 (^{238}U), ^{230}Th, and ^{226}Ra.

4.1.1 Sampling Procedure

To determine airborne concentrations of radionuclides transported via airborne particulates, airborne particulates are collected onto 2-inch-diameter borosilicate glass fiber filter media by use of high-volume air samplers (RADeCO Model HD28 or equivalent air sampler). One air sampler is operated at each off-site monitoring station to collect airborne particulates continuously onto the filter media for a duration of 7 days. The air samplers are operated at a flow rate of at least 2.0 cubic feet per minute to yield a minimum air sample volume of 20,160 cubic feet (571 cubic meters [m^3]). At the end of the sampling period, the sampled filter is submitted for laboratory analysis, a new filter is installed, and a new 7-day sampling period begins.

The filters are analyzed by TestAmerica of Earth City, Missouri, for gross alpha, gross beta, gamma-emitting radionuclides, isotopic uranium, isotopic thorium, and total alpha-emitting radium. The laboratory results are reported as total activity (in picoCuries [pCi]) per filter. Total air volume drawn through the filter is recorded by the field sampler at the time of filter collection. Air concentrations are calculated by dividing the per filter total activity (in pCi) by the volume of air drawn through the filter (in m^3) to yield an air concentration in units of pCi/m^3.

4.1.2 Data Validation, Verification, and Usability

As laboratory analytical reports are received for the airborne particulate radionuclide analysis, START reviews and qualifies the data according to EPA Contract Laboratory Program guidelines (EPA 2008), the *Multi-Agency Radiological Laboratory Analytical Protocols Manual* (EPA 2004), and other criteria

WLLFOIA4312 - 004 - 0090610

specified in the applicable methods. Findings of these reviews are documented in a data validation report that is appended to each analytical laboratory report and included in the data deliverable packages (see Tetra Tech 2014b, c, d, e, f). Suggested qualifications to the data from START's review are indicated by qualifier flags that accompany the data presented herein. Overall, review of the laboratory analytical data packages indicated that quality of the airborne particulate data was acceptable and usable as qualified for the intended purposes of those data.

4.1.3 Gross Alpha Results and Evaluation

The following describes gross alpha results from weekly air filter samples collected from May 8 through October 9, 2014.

Summary Statistics

Table 1 lists frequency of detection and minimum, median, and maximum gross alpha concentrations.

TABLE 1

SUMMARY STATISTICS OF GROSS ALPHA RESULTS

Summary Statistic	Station 1	Station 2	Station 3	Station 4	Station 5 (background)
Detections[1]	18/23	17/23	15/23	8/23	14/23
Minimum Concentration[2]	3.25E-04 U	1.93E-04 U	2.81E-04 U	1.76E-04 U	1.10E-04 U
Median Concentration[3]	5.95E-04	6.00E-04	6.32E-04	6.01E-04	5.71E-04
Maximum Concentration[4]	1.58E-03 J	1.68E-03 J	1.58E-03 J	1.28E-03 J	1.34E-03 J

Notes:

All concentrations in picoCuries per cubic meter (pCi/m^3)

J Indicates an estimated result

U Indicates a non-detected result

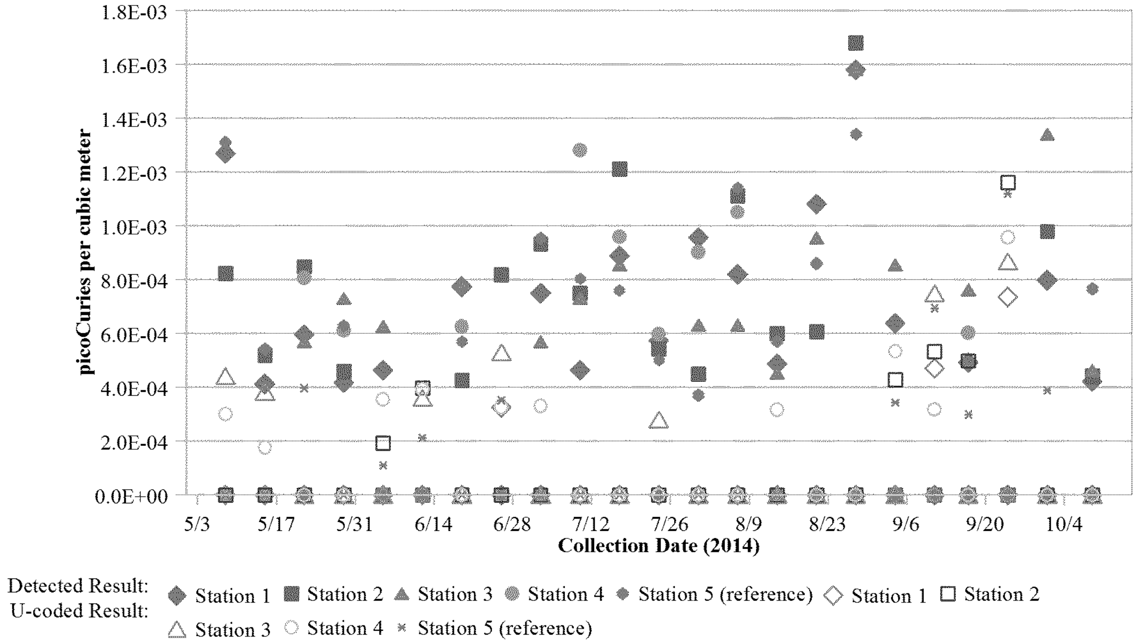
1 Number of detections / number of samples. U-coded results were counted as not detected.
2 Includes lowest reported value among both U-coded and non-U-coded results.
3 Median concentration among U-coded and non-U-coded results.
4 Maximum detected (non-U-coded) concentration.

Time Series Plot

Exhibit 1 is a time series graph of the gross alpha results. This graph shows no discernable trends or patterns in the data.

EXHIBIT 1

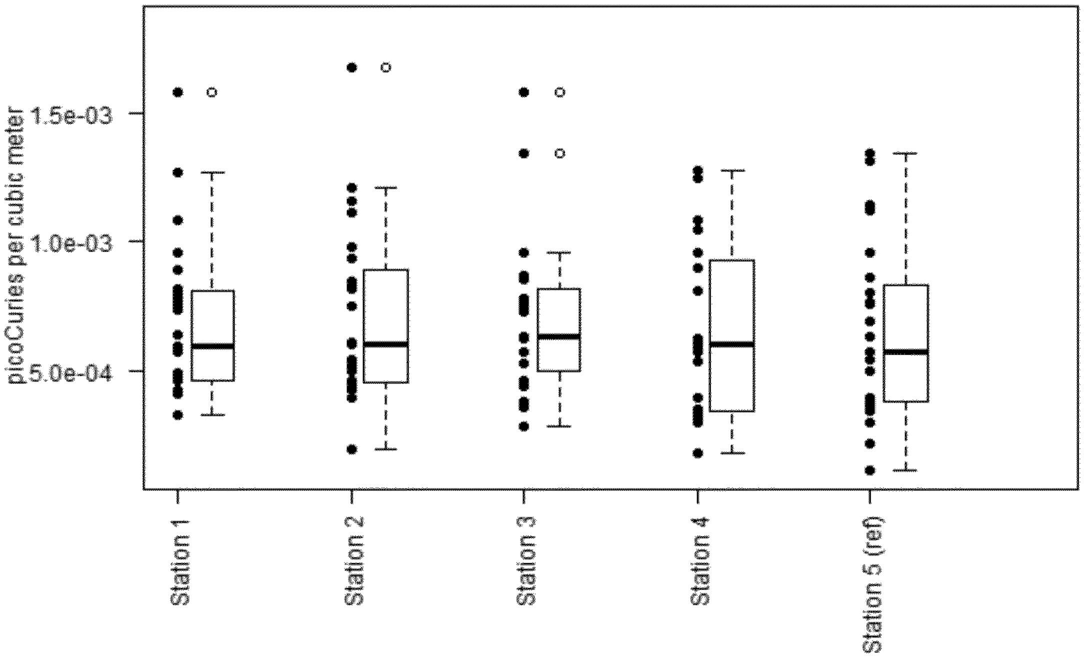
TIME SERIES PLOT OF GROSS ALPHA ACTIVITY



ws box plots of the gross alpha results. These plots suggest similar median concentrations ions among the five monitoring stations. The box plots suggest several upper end outlier concentrations (indicated by open circles) for Stations 1, 2, and 3. Data users should be aware of these suggested outliers because their representation of the parameter being measured is uncertain. The cause of the suggested outliers in the gross alpha data is unknown, but outliers are often attributed to measurement error or can occur by chance in any distribution. Regarding the suggested outliers in the gross alpha data, one should consider that (1) maximum detected gross alpha concentrations among the five stations were within an order of magnitude (the station maximums ranged from 1.28E-03 to 1.68E-03 pCi/m^3), (2) suggested outliers occurred at multiple stations, and (3) statistical analyses suggest that the median/mean characteristics of the distributions were similar among the five stations, and that no station tended to yield higher or lower results than any other station (see Section 4.1.8).

EXHIBIT 2

BOX PLOTS OF GROSS ALPHA ACTIVITY



4.1.4 Gross Beta Results and Evaluation

The following describes the gross beta results from weekly air filter samples collected from May 8 through October 9, 2014.

<u>Summary Statistics</u>

Table 2 lists frequency of detection and minimum, median, and maximum gross beta concentrations.

TABLE 2

SUMMARY STATISTICS OF GROSS BETA RESULTS

Summary Statistic	Station 1	Station 2	Station 3	Station 4	Station 5 (reference)
Detections[1]	23/23	23/23	23/23	23/23	23/23
Minimum Concentration	1.50E-02	1.48E-02	1.54E-02	1.48E-02	1.21E-02 J
Median Concentration	1.95E-02	1.89E-02	1.89E-02	1.84E-02	1.83E-02
Maximum Concentration	3.27E-02	3.59E-02	3.52E-02	3.70E-02	3.53E-02

Notes:

All concentrations in picoCuries per cubic meter (pCi/m^3)

J Indicates an estimated result

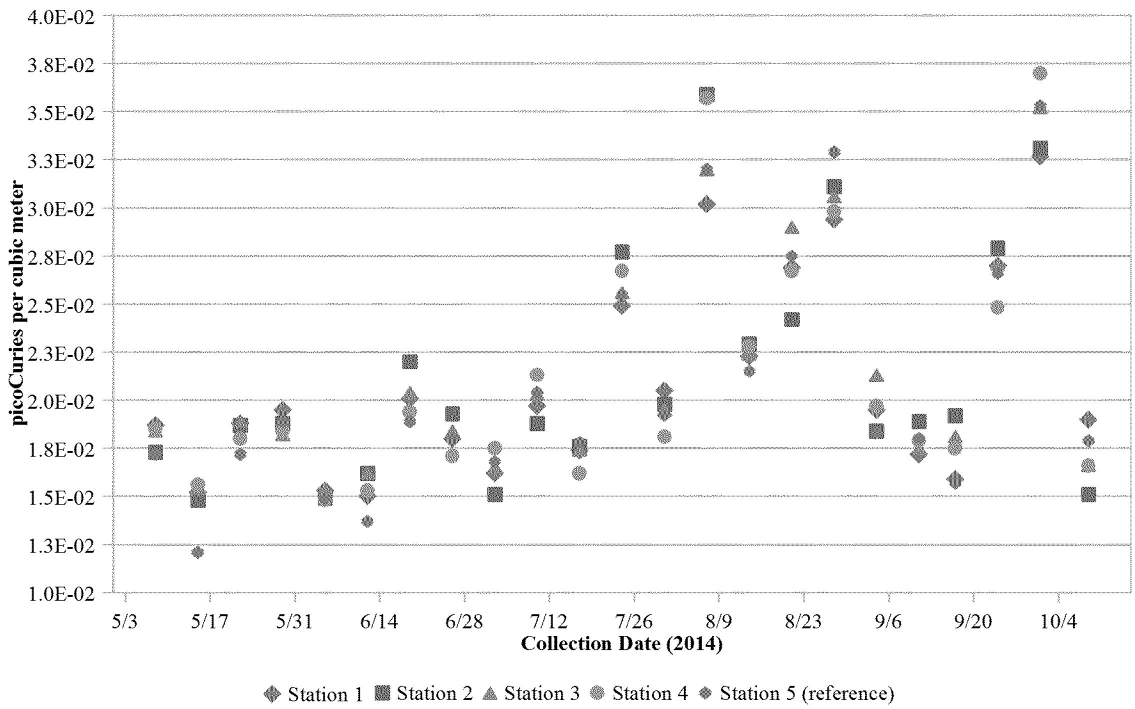
[1] Number of detections / number of samples (no gross beta results are U-coded).

Time Series Plot

The gross beta time series plot in Exhibit 3 shows no discernable trends or patterns in the data, except that gross beta results from filters collected during the same week appear to be related by a common component that varies irregularly from week to week. The cause of this is unknown, but possibly this is attributable to naturally occurring, short-lived radon daughters collected onto the filters that variably contribute to the gross beta concentrations (depending on the amount of time between filter collection and analysis allowing for decay).

EXHIBIT 3

TIME SERIES PLOT OF GROSS BETA ACTIVITY

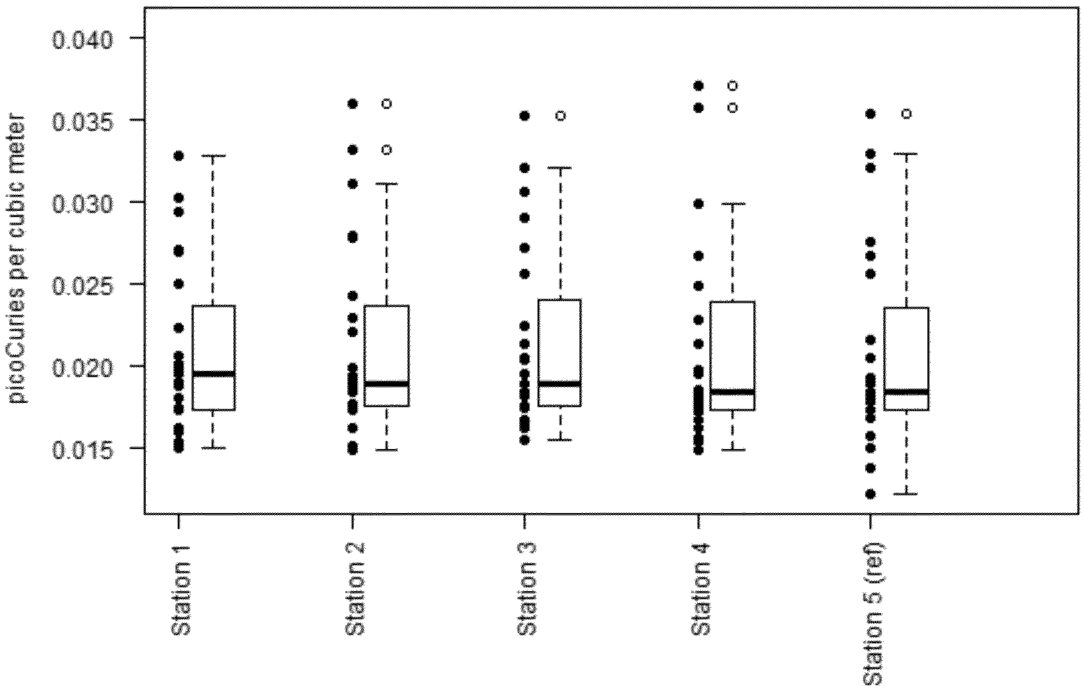


Box Plots

Exhibit 4 shows box plots of the gross beta results. These plots suggest similar median concentrations and distributions among the five monitoring stations. The box plots suggest several upper end outlier concentrations (indicated by open circles) at Stations 2, 3, 4, and 5. Data users should be aware of these suggested outliers because their representation of the parameter being measured is uncertain. The cause of the suggested outliers in the gross beta data is unknown, but outliers are often attributed to measurement error or can occur by chance in any distribution. Regarding the suggested outliers in the gross beta data, one should consider that (1) maximum detected gross beta concentrations among the five stations were within an order of magnitude (the station maximums ranged from 3.27E-02 to 3.70E-02 pCi/m^3), (2) suggested outliers occurred at multiple stations (including Station 5, the reference station), and (3) statistical analyses suggest that median/mean characteristics of the distributions were similar among the five stations, and that no station tended to yield higher or lower results than any other station (see Section 4.1.8).

EXHIBIT 4

BOX PLOTS OF GROSS BETA ACTIVITY



4.1.5 Uranium-238 Results and Evaluation

The following describes ^{238}U results from weekly air filter samples collected from May 8 through September 24, 2014.

Summary Statistics

Table 3 lists frequency of detection and minimum, median, and maximum ^{238}U concentrations.

WLLFOIA4312 - 004 - 0090616

TABLE 3

SUMMARY STATISTICS OF URANIUM-238 RESULTS

Summary Statistic	Station 1	Station 2	Station 3	Station 4	Station 5 (reference)
Detections[1]	11/21	13/21	13/21	9/21	9/21
Minimum Concentration[2]	-1.03E-05 U	4.43E-06 U	-4.42E-05 U	2.75E-05 U	-2.25E-05 U
Median Concentration[3]	1.26E-04	1.21E-04	1.18E-04	9.15E-05	1.02E-04
Maximum Concentration[4]	6.22E-04 J	9.47E-04	3.86E-04 J	3.07E-04 J	1.67E-04 J

Notes:

All concentrations in picoCuries per cubic meter (pCi/m[3])

J Indicates an estimated result
U Indicates a non-detected result

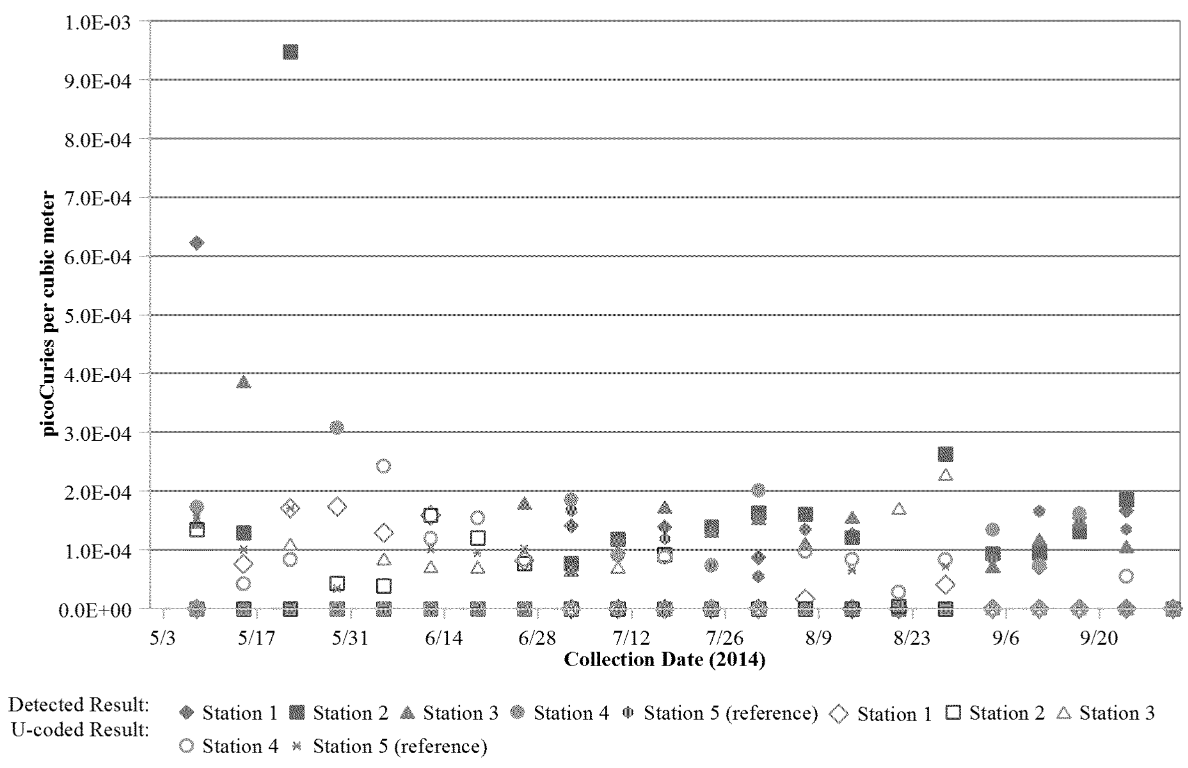
[1] Number of detections / number of samples. U-coded results were counted as not detected.
[2] Includes lowest reported value among both U-coded and non-U-coded results.
[3] Median concentration among U-coded and non-U-coded results.
[4] Maximum detected (non-U-coded) concentration.

Time Series Plot

The time series plot of ^{238}U results in Exhibit 5 shows no discernable trends or patterns in the data.

EXHIBIT 5

TIME SERIES PLOT OF URANIUM-238



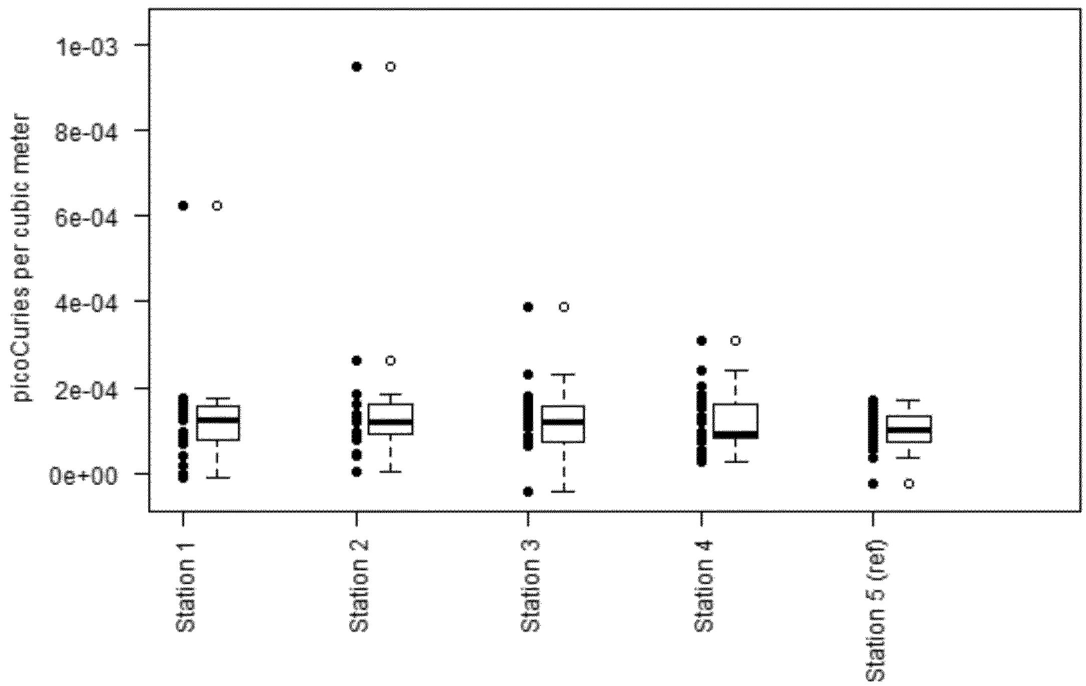
WLLFOIA4312 - 004 - 0090617

Box Plots

Exhibit 6 shows box plots of the ^{238}U results. As with the gross alpha and beta results, these plots suggest similar median concentrations and distributions among the five monitoring stations. The box plots suggest several upper end outlier concentrations (indicated by open circles) at Stations 1, 2, 3, and 4. Data users should be aware of these suggested outliers because their representation of the parameter being measured is uncertain. The cause of the suggested outliers in the ^{238}U data is unknown, but outliers are often attributed to measurement error or can occur by chance in any distribution. Regarding the suggested outliers in the ^{238}U data, one should consider that (1) maximum detected ^{238}U concentrations among the five stations were within an order of magnitude (the station maximums ranged from 1.67E-04 to 9.47E-04 pCi/m^3), (2) suggested outliers occurred at multiple stations, and (3) statistical analyses suggested that median/mean characteristics of the distributions were similar among the five stations, and that no station tended to yield higher or lower results than any other station (see Section 4.1.8).

EXHIBIT 6

BOX PLOTS OF URANIUM-238 ACTIVITY



4.1.6 Thorium-230 Results and Evaluation

The following describes ^{230}Th results from weekly air filter samples collected from May 8 through September 24, 2014.

Summary Statistics

Table 4 lists frequency of detection and minimum, median, and maximum ^{230}Th concentrations.

TABLE 4

SUMMARY STATISTICS OF THORIUM-230 RESULTS

Summary Statistic	Station 1	Station 2	Station 3	Station 4	Station 5 (reference)
Detections[1]	20/21	18/21	20/21	20/21	19/21
Minimum Concentration[2]	3.23E-04 J	3.07E-04 U	3.13E-04 J	3.05E-04 J	2.71E-04 U
Median Concentration[3]	4.94E-04	5.86E-04	5.99E-04	6.06E-04	5.78E-04
Maximum Concentration[4]	4.37E-03	1.36E-03 J	8.86E-04 J	1.06E-03 J	1.99E-03 J

Notes:

All concentrations in picoCuries per cubic meter (pCi/m^3)

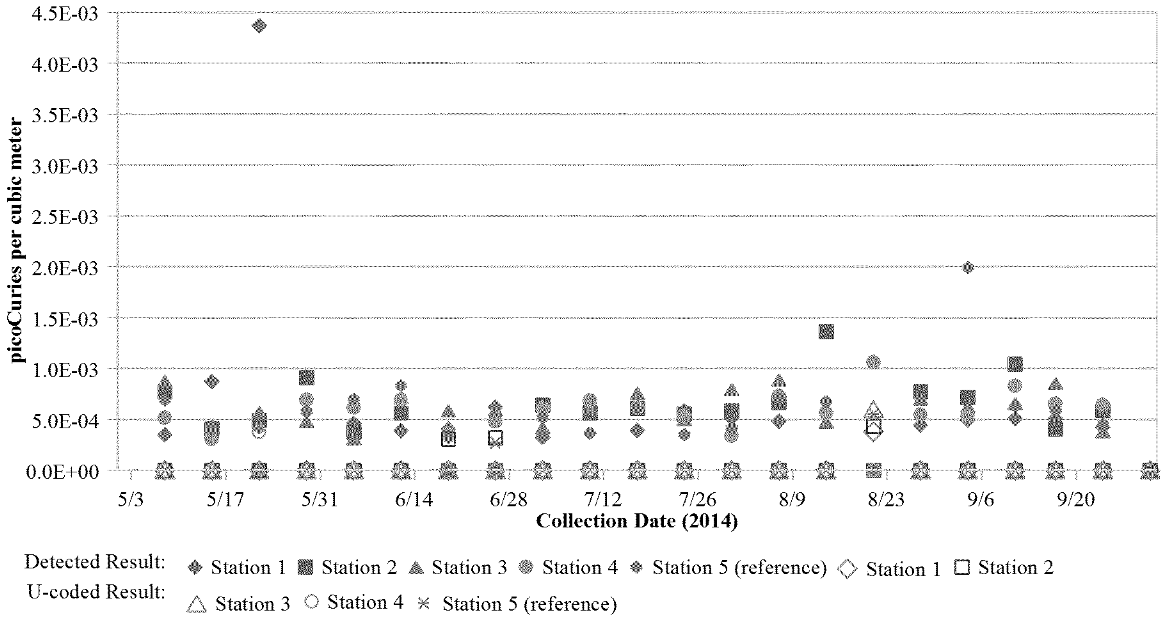
J Indicates an estimated result
U Indicates a non-detected result
1 Number of detections / number of samples. U-coded results were counted as not detected.
2 Includes lowest reported value among both U-coded and non-U-coded results.
3 Median concentration among U-coded and non-U-coded results.
4 Maximum detected (non-U-coded) concentration.

Time Series Plot

The time series plot of ^{230}Th results in Exhibit 7 shows no discernable trends or patterns in the data.

EXHIBIT 7

TIME SERIES PLOT OF THORIUM-230



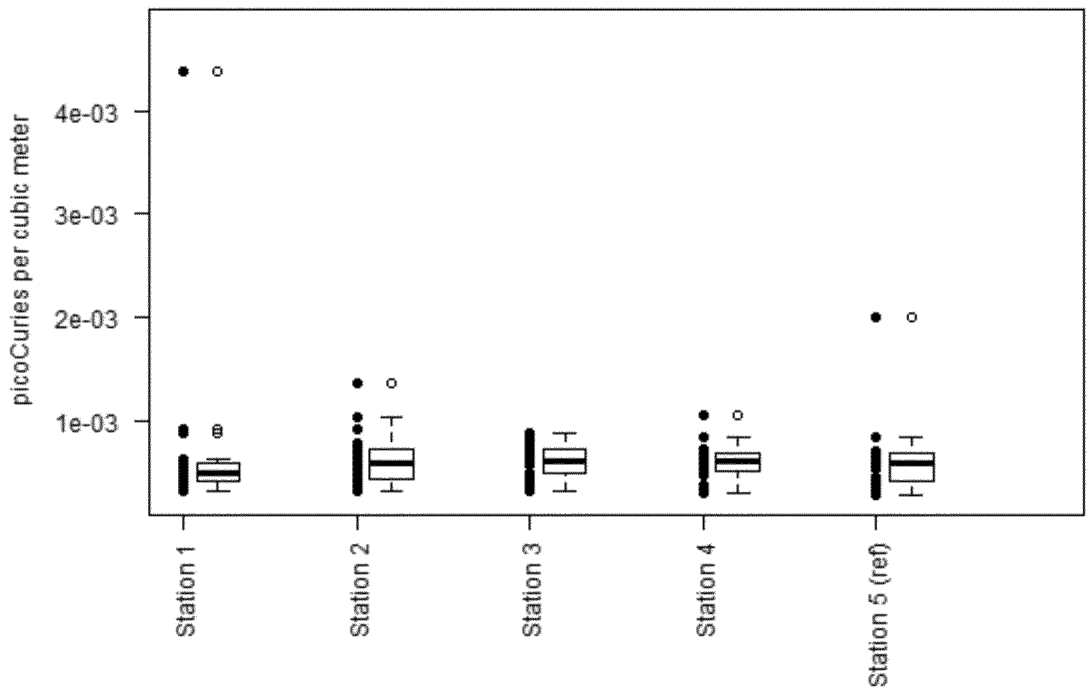
WLLFOIA4312 - 004 - 0090619

Box Plots

Exhibit 8 shows box plots of the ^{230}Th results. As with the aforementioned gross alpha/beta and ^{238}U results, these plots suggest similar median concentrations and distributions among the five monitoring stations. The box plots suggest several upper end outlier concentrations (indicated by open circles) at Stations 1, 2, 4, and 5. Data users should be aware of these suggested outliers because their representation of the parameter being measured is uncertain. The cause of the suggested outliers in the ^{230}Th data is unknown, but outliers are often attributed to measurement error or can occur by chance in any distribution. Regarding the suggested outliers in the ^{230}Th data, one should consider that (1) maximum detected ^{230}Th concentrations among the five stations were within an order of magnitude (the station maximums ranged from 8.86E-04 to 4.37E-03 pCi/m^3), (2) suggested outliers occurred at multiple stations (including Station 5, the reference station), and (3) statistical analyses suggested that the median/mean characteristics of the distributions were similar among the five stations, and that no station tended to have higher or lower results than any other station (see Section 4.1.8).

EXHIBIT 8

BOX PLOTS OF THORIUM-230 ACTIVITY



4.1.7 Total Alpha-Emitting Radium Results and Evaluation

The following describes the total alpha-emitting radium results from weekly air filter samples collected from May 8 through September 24, 2014. Although the radium isotope of interest for WLLS is ^{226}Ra, as a cost-savings measure and to reduce analysis time, the samples were first analyzed via a method that reports total alpha-emitting radium, which includes the radium isotopes ^{223}Ra, ^{224}Ra, and ^{226}Ra. If a sample yielded a total alpha-emitting radium result exceeding 5 pCi per filter (corresponding to an air concentration of 8.8E-3 pCi/m^3 for the targeted air volume of 571 m^3), that sample was to be re-analyzed via a ^{226}Ra-specific method. However, none of the total alpha-emitting radium results exceeded 5 pCi per filter, although the laboratory mistakenly prepared the samples collected on May 15, 2014, for a ^{226}Ra-

specific analysis, and the reported results were ^{226}Ra concentrations (these data are flagged "□2 2 □□").

Summary Statistics

Table 5 lists frequency of detection and minimum, median, and maximum total alpha-emitting radium concentrations.

TABLE 5

SUMMARY STATISTICS OF TOTAL ALPHA-EMITTING RADIUM RESULTS

Summary Statistic	Station 1	Station 2	Station 3	Station 4	Station 5 (reference)
Detections[1]	2/21	4/21	3/21	1/21	2/21
Minimum Concentration[2]	-2.50E-04 U	-2.01E-04 U	-4.04E-05 U	-4.86E-04 U	-4.34E-04 UG
Median Concentration[3]	3.97E-04	5.14E-04	4.55E-04	3.66E-04	4.68E-04
Maximum Concentration[4]	1.10E-03 J	1.80E-03 JG	2.01E-03	3.66E-04 J □2 2 □□	4.40E-03

Notes:

All concentrations in picoCuries per cubic meter (pCi/m^3)

□2 2 □□ Indicates the result is from a radium-226 specific laboratory method

G The sample minimum detectable concentration is greater than the requested reporting limit
J Indicates an estimated result
U Indicates a non-detected result

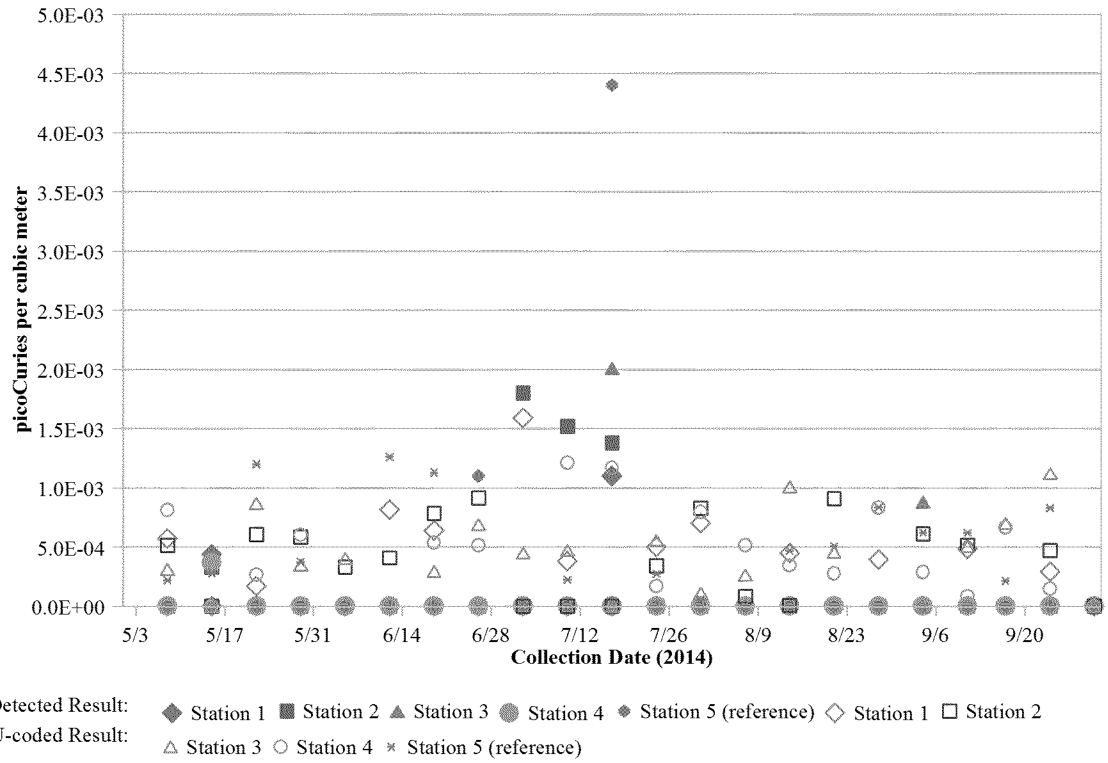
[1] Number of detections / number of samples. U-coded results were counted as not detected.
[2] Includes lowest reported value among both U-coded and non-U-coded results.
[3] Median concentration among U-coded and non-U-coded results.
[4] Maximum detected (non-U-coded) concentration.

Time Series Plot

The total alpha-emitting radium time series plot in Exhibit 9 shows no discernable trends or patterns in the data. Notably, almost 90 percent of the data are U-coded, indicating a non-detect result.

EXHIBIT 9

TIME SERIES PLOT OF TOTAL ALPHA-EMITTING RADIUM



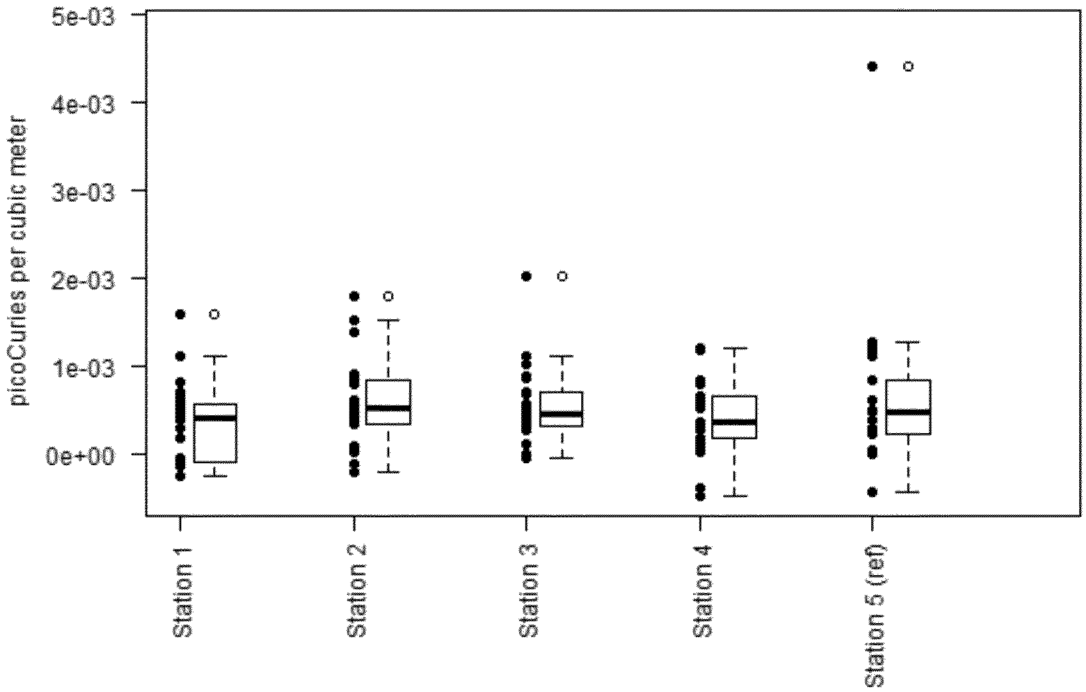
Bo

Ex)x plots of the total-alpha emitting radium results; however, utility of these plots is lim rly 90 percent of the total-alpha emitting radium results were non-detect (the box plots show both U-coded and non-U-coded results).

WLLFOIA4312 - 004 - 0090623

EXHIBIT 10

BOX PLOTS OF TOTAL ALPHA-EMITTING RADIUM RESULTS



4.1.8 Statistical Analyses

Two statistics tests—the Kruskal-Wallis and Friedman tests—were used to test for differences in gross alpha/beta results, and concentrations of ^{238}U, ^{230}Th, and total alpha-emitting radium (including ^{226}Ra) among the five monitoring stations. The Kruskal-Wallis and Friedman tests are non-parametric statistical tests that compare multiple treatments (such as the multiple monitoring locations). The Kruskal-Wallis test assumes data sets are independent, whereas the Friedman Rank Sum test accounts for related (or cluster-correlated) data. Because the time-series plots suggested that some data were unrelated (such as the gross-alpha results that showed no obvious clustering from week to week) and some were related (such as the gross-beta results showing obvious clustering from week to week), both tests were used. The data underwent the Kruskal-Wallis and Friedman tests by use of the statistical software package R (see Appendix D for the input data sets, R scripts, and R output). Table 6 summarizes the Kruskal-Wallis and Friedman test results.

The Kruskal-Wallis test did not identify significant differences in mean/median characteristics of the data examined (gross alpha, gross beta, ^{238}U, ^{230}Th, and total alpha-emitting radium) among the five monitoring stations, and the Friedman test found no tendency for one station to yield larger or smaller

WLLFOIA4312 - 004 - 0090624

measurements than any other station.

TABLE 6

SUMMARY OF STATISTICAL TEST EXAMINING AIRBORNE PARTICULATE RADIONUCLIDE RESULTS

Statistical Test	Result of Statistical Test				
	Gross Alpha	**Gross Beta**	**^{238}U**	**^{230}Th**	**Total Alpha-Emitting Radium**
Kruskal-Wallis[1]	No significant differences ($p = 0.924$)	No significant differences ($p = 0.971$)	No significant differences ($p = 0.811$)	No significant differences ($p = 0.464$)	No significant differences ($p = 0.483$)
Friedman[2]	No station tended to have larger or smaller measurements than any other ($p = 0.745$)	No station tended to have larger or smaller measurements than any other ($p = 0.265$)	No station tended to have larger or smaller measurements than any other ($p = 0.621$)	No station tended to have larger or smaller measurements than any other ($p = 0.504$)	No station tended to have larger or smaller measurements than any other ($p = 0.122$)

Notes:

1 Results from the statistical software package R version 3.1.2 using the non-parametric Kruskal-Wallis test to compare the various radionuclide mean/median characteristics among the five monitoring stations. A p-value equal to or less than 0.05 suggests significant differences in mean/median characteristics among the stations. A p-value of greater than 0.05 suggests that the mean/median characteristics among the stations are comparable. See Appendix D to examine the Kruskal-Wallis test output from R.

2 Results from the statistical software package R version 3.1.2 using the non-parametric Friedman test to identify tendencies for measurements from one station to be larger or smaller than at any other station. A p-value equal to or greater than 0.05 suggests no tendency for one station to yield larger or smaller measurements than any other station. A p-value less than 0.05 suggests that one or more stations tended to yield measurements larger or smaller than other stations. See Appendix D to examine the test output from R.

4.1.9 Comparison of Gross Alpha to Radionuclide-Specific Results

The radionuclide-specific results examined in this section—^{238}U, ^{230}Th, and total alpha-emitting radium results—were compared to gross alpha results. Because each of these radionuclides (^{238}U, ^{230}Th, as well as ^{223}Ra, ^{224}Ra, and ^{226}Ra included in the total alpha-emitting radium result) is an alpha-emitting radionuclide, its concentration in a sample will be a component of (and not exceed) the gross (or total) alpha activity of the sample. To determine if the data conform to this relationship, the detected (non-U-coded) radionuclide-specific results were plotted against detected (non-U-coded) gross alpha results (see Exhibits 11-13). Each plot has a line representing a 1:1 ratio for the subject alpha-emitting radionuclide vs gross alpha (i.e., points on the line would indicate equal reported alpha-emitting radionuclide and gross alpha concentrations). Points above this line represent samples exhibiting a radionuclide-specific result that was less than its gross alpha result, indicating conforming data because the alpha-emitting radionuclide result was a component of, and did not exceed, the gross alpha result. Points below the 1:1 line represent a sample with an alpha-radionuclide result greater than its gross alpha result. This would not conform to the expectation that alpha-emitting radionuclide results would be less than gross alpha results (some nonconforming data may be expected when results are near the method detection limit).

EXHIBIT 11

URANIUM-238 AND GROSS ALPHA RESULTS

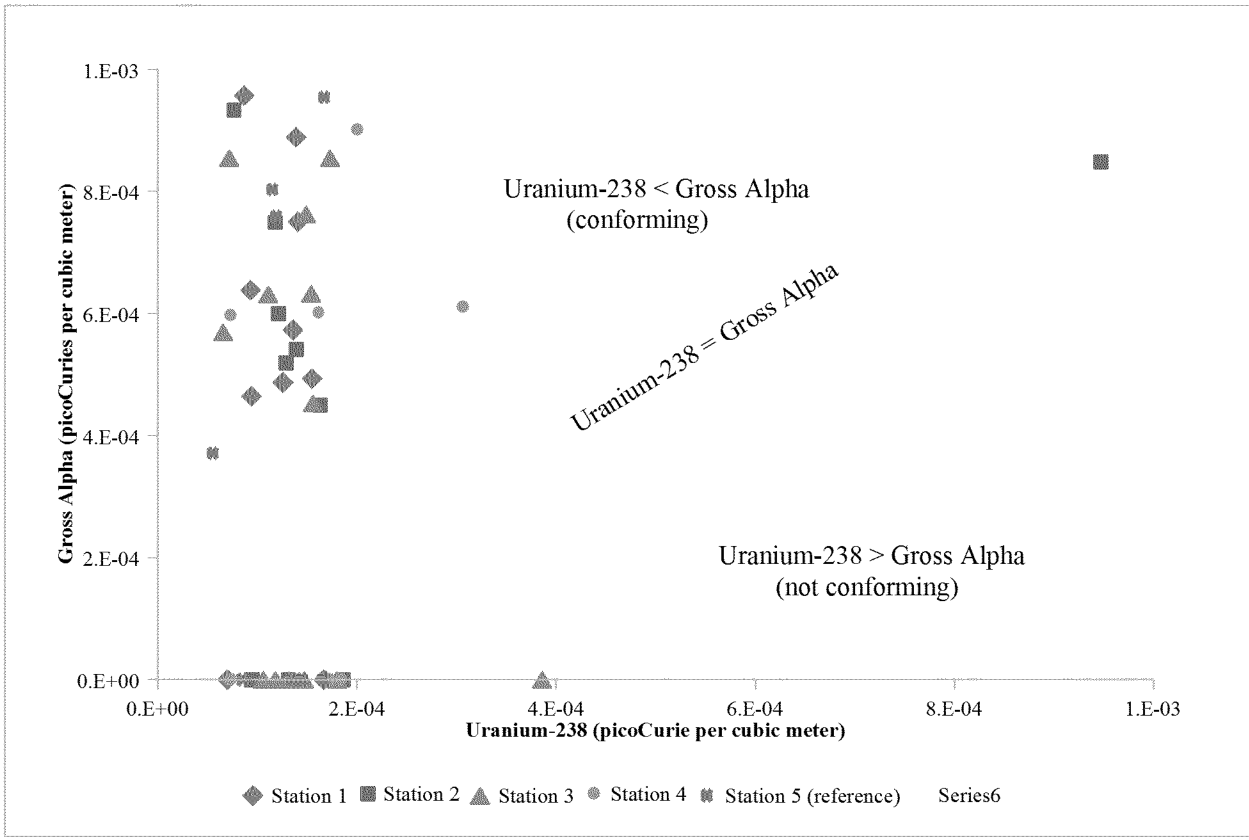


Exhibit 11 shows that all but one of the ^{238}U results conform to their corresponding gross alpha results. The one exception was the sample collected at Station 2 on May 22, 2014, which yielded a ^{238}U result of 9.47E-04 pCi/m^3 (notably the highest ^{238}U result among the data evaluated) and a gross alpha result of 8.48E-04 pCi/m^3.

EXHIBIT 12

THORIUM-230 AND GROSS ALPHA RESULTS

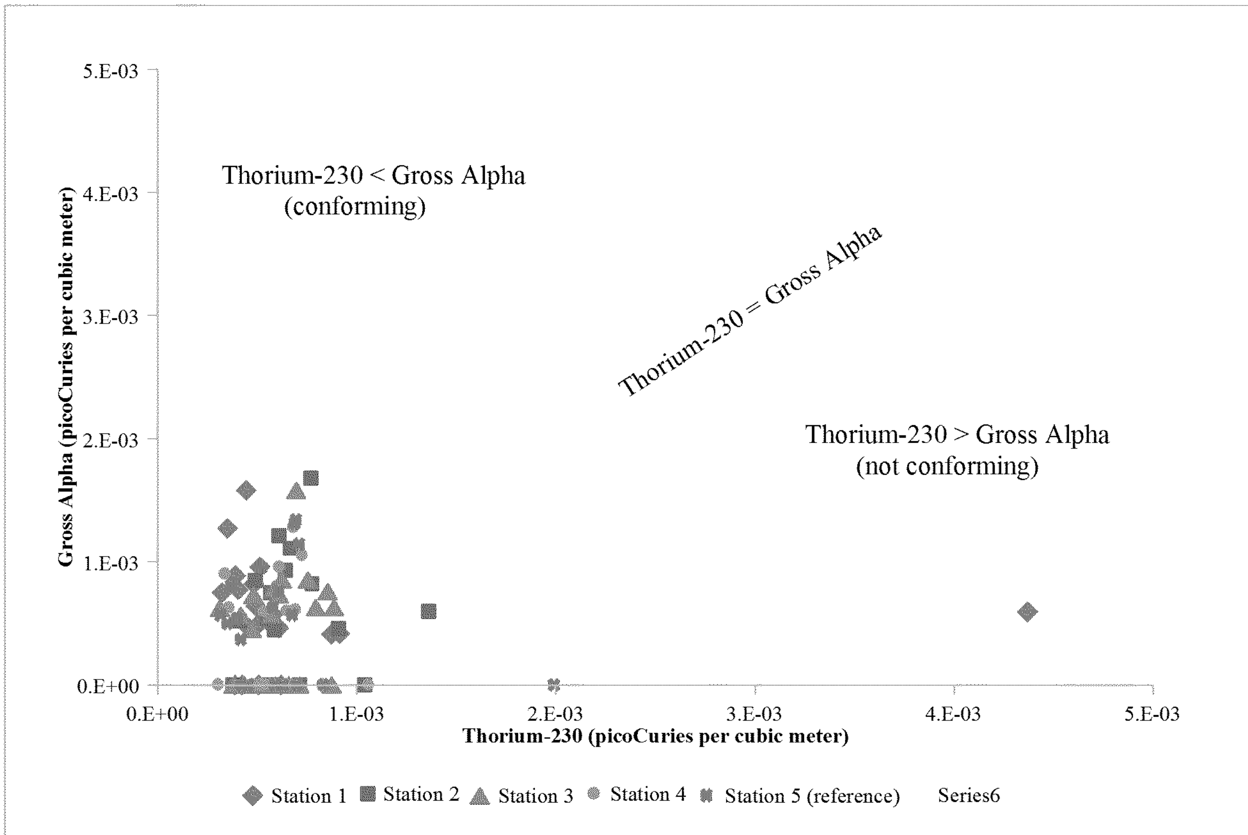


Exhibit 12 indicates numerous ^{230}Th results that do not conform to the corresponding gross alpha results. Many of these occurrences possibly relate to nearness of results to the laboratory detection capability (note that all results but one are in a cluster spanning the low end of the 1:1 line). The highest ^{230}Th result of 4.37E-03 pCi/m^3 (from the sample collected at Station 1 on May 22, 2014) notably does not conform to its corresponding gross alpha result of 5.95E-04 pCi/m^3. This observation prompts some speculation regarding its representativeness of actual ^{230}Th concentrations.

EXHIBIT 13

TOTAL ALPHA-EMITTING RADIUM AND GROSS ALPHA RESULTS

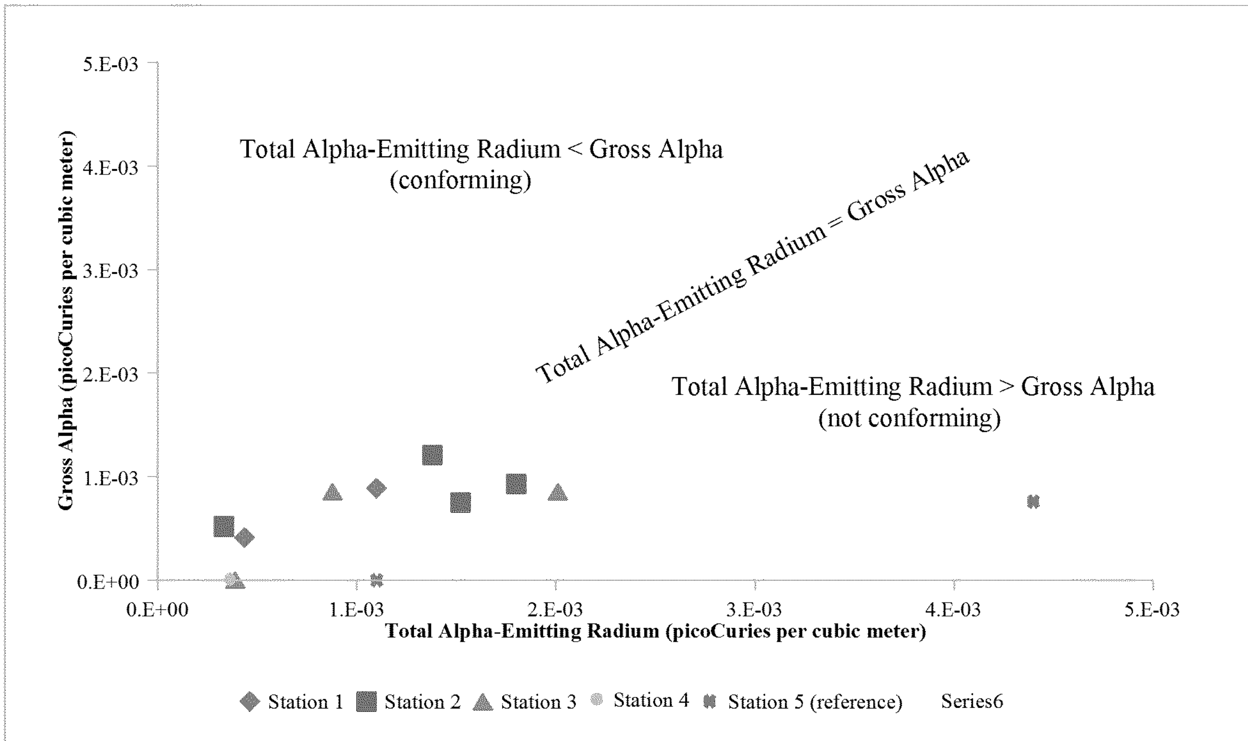


Exhibit 13 shows that most of the detected total-alpha emitting radium results do not conform to their corresponding gross alpha result. Many of these occurrences possibly relate to nearness of results to the laboratory detection capability, but as observed with the ^{238}U and ^{230}Th data, the highest total alpha-emitting radium result of 4.40E-03 pCi/m^3 (from the sample collected at Station 5 on July 7, 2014) notably does not conform to its corresponding gross alpha result of 7.59E-04 pCi/m^3. Likewise, this observation prompts some speculation that this maximum total alpha-emitting radium result is possibly unrepresentative.

Overall, a comparison of specific alpha-emitting radionuclide results (^{238}U, ^{230}Th, and total alpha-emitting radium results) to their corresponding gross alpha results indicated occasions of nonconformance of the radionuclide-specific result to its gross alpha result (because the radionuclide-specific result exceeded its corresponding gross alpha result). Data users should be aware of this characteristic in the data.

4.1.10 Recommendations for Sampling Optimization

Baseline airborne concentrations of radionuclide parameters of interest at the five monitoring stations have been well established via air particulate sampling since May 2014. Continued air particulate sampling is unlikely to provide additional information regarding ambient baseline conditions. However, if continued sampling is desired, Tetra Tech suggests reducing the routine analytical parameters to gross alpha and gross beta, and discontinuing routine radionuclide-specific analyses of the air filter samples (that is, discontinuing isotopic uranium/thorium and total alpha-emitting radium analyses). The recommended approach for continued sampling would be to first analyze each sample for gross alpha and gross beta, and if a gross alpha or beta result exceeds a pre-determined threshold (determined through an appropriate data quality objectives [DQO] process), subject the same sample to radionuclide-specific analyses.

4.2 RADON MONITORING

Radon (^{222}Rn) has been identified as a radiological parameter of interest because it is a decay product of ^{226}Ra, a radionuclide of concern at WLLS. ^{222}Rn is also generated by decay of ^{226}Ra naturally occurring in soil and rock, and a significant portion of this ^{222}Rn is naturally released from the ground into the atmosphere because, as a noble gas, radon becomes unbound to soil and rock. The rate of release from the ground and concentration of ^{222}Rn in outdoor air depend on a number of factors including local geology, soil porosity, soil moisture, and atmospheric pressure. Outdoor ^{222}Rn levels fluctuate but are normally around 0.4 pCi/L of air (EPA 2012).

4.2.1 Sampling Procedure

Electret ion chamber radon detectors (Rad Elec E-PERM®) equipped with high-volume chamber ("H-chamber") short-term ("ST") electrets were used to assess ^{222}Rn levels at each off-site monitoring station. Electret measurements proceed by use of an Electret Voltage Reader to measure a beginning and final electrical charge on the electret exposed for a specified time period. In addition, one pocket ion chamber per station (co-located with the electret ion chamber radon detectors) provides a gross gamma activity measurement used in the final ^{222}Rn measurement calculation (see Appendix C to examine this calculation). Electrets and pocket ion chambers are read weekly to yield a ^{222}Rn measurement that has been continuously integrated (averaged) over the week-long exposure duration. Three electret ion chambers are deployed per off-site monitoring station to provide redundant measurements in case of a device failure, and to provide an indication of total method precision.

WLLFOIA4312 - 004 - 0090629

4.2.2 Data Validation, Verification, and Usability

^{222}Rn measurements were reviewed by the START project manager and were qualified as necessary based on sampling deviations noted in the field or any irregularities in the data. Qualifiers assigned to the radon measurements included the following:

Off-Scale Pocket Ion Chamber Readings (G1)
Several pocket ion chamber exposure readings exceeded the 2.0 milliroentgen (mR) scale of the pocket ion chamber; for these measurements, a final exposure reading of 2.0 mR (the maximum scale reading) was assumed, possibly resulting in a low bias to the gamma exposure value input to the calculation of ^{222}Rn concentration. Because higher gamma exposure values induce larger subtractions to the final ^{222}Rn concentration, ^{222}Rn concentrations associated with off-scale pocket ion chamber readings (those flagged "G1") may be biased high.

Electret Measurements Below Usable Voltage (LV1, LV2, and LV3)
Per the manufacturer, an electret showing a reading of less than 200 volts should not be used for measurements because the weaker electrostatic field is not as consistent in collecting the ions efficiently. Some replicate measurements were associated with a final reading below 200 volts; these readings were not used in calculation of the weekly station ^{222}Rn measurement. Weekly station measurements associated with electret readings below 200 volts were flagged either "LV1" (one replicate was below 200 volts), "LV2" (two of the three replicate electrets fell below 200 volts), or "LV3" (each of the three replicates fell below 200 volts). Only one weekly ^{222}Rn measurement was flagged "LV3" (the measurement at Station 4 from June 20-27); because each of the three replicate measurements was unusable, no ^{222}Rn concentration was reported. Starting on October 21, 2014, the corrective action of removing from service any electret with a reading of less than 300 volts was taken to decrease occurrences of final electret readings below 200 volts.

Missing and Erroneous Measurements (V1, V2, and E)
Vandalism affected ^{222}Rn measurements at Station 4 during weeks ending July 3 and 11, 2014 (see Appendix B, Table B-6 for explanations of qualifiers "V1" and "V2"). One measurement (Station 5, week ending June 27, 2014) was associated with one electret measurement that yielded a negative ^{222}Rn concentration; this value was not included in the weekly calculated ^{222}Rn concentration for the station, which was flagged "E."

WLLFOIA4312 - 004 - 0090630

Replicate Measurements Identified as Outliers by Statistical Evaluation (OH and OL)

Following determination of data usability with respect to the aforementioned qualifiers, an assessment for low and high outliers was conducted where three usable replicate measurements remained (a minimum of three measurements is required to statistically assess for outliers). Dixon's statistical procedure for outlier identification was used to assess for outliers; this procedure was implemented as described in *U.S. Nuclear Regulatory Commission NUREG 1475*, Chapter 26.4, assuming a probability of erroneously labeling an observation as an outlier (α) of 0.05. Use of Dixon's procedure was also recommended by Rad Elec, Inc., the manufacturer of the radon detectors used at WLLS, to identify any suspect measurements. Where an outlier was detected, it was not reflected in the reported weekly station ^{222}Rn concentration (the replicate ^{222}Rn concentrations are listed in Appendix C, Table C-1). The qualifiers "OH" and "OL" indicate that one of the three replicate ^{222}Rn measurements was identified either as high (OH) or low (OL), and was not used to calculate the reported mean weekly station ^{222}Rn concentration.

Some weekly measurements could not be assessed for identification of outliers using Dixon's procedure because fewer than three replicate measurements were available. Data users should be aware that because these weekly station measurements were not amenable to this procedure, they may be less robust than measurements amenable to Dixon's procedure that led to removal of detected outliers from the reported average result. Measurements flagged "LV1," "LV2," and "E" are affected because these derived from fewer than three usable replicate measurements; these measurements are noted with an asterisk (*) in the radon time series plot on Exhibit 14.

4.2.3 Radon Results and Evaluation

The following describes ^{222}Rn results from weekly monitoring from April 25 through October 24, 2014.

Summary Statistics

For each monitoring station, Table 7 lists minimum, median, and maximum ^{222}Rn concentrations.

TABLE 7

SUMMARY STATISTICS OF RADON-222 RESULTS

Summary Statistic	Station 1	Station 2	Station 3	Station 4	Station 5 (reference)
Number of Measurements	26	26	26	24	26
Minimum Concentration	0.19	0.15 G1 LV1	0.12	0.09	0.11 OH
Median Concentration	0.25	0.27	0.25	0.19	0.25
Maximum Concentration	0.87 LV1	1.81 LV2	1.88 LV1	0.83	1.45 LV1

WLLFOIA4312 - 004 - 0090631

Notes:

All concentrations in picoCuries per liter (pCi/L)

G1 Final dose reading of pocket ion chamber exceeded the scale of 2.0 milliroentgens (mR), and a final reading of 2.0 was assumed. The reported ^{222}Rn result may be biased high.

OH Indicates one of the three replicate ^{222}Rn measurements was identified as a high outlier based on Dixon's procedure for outlier identification (see U.S. Nuclear Regulatory Commission NUREG 1475, Chapter 26.4), assuming a probability of erroneously labeling an observation as an outlier (α) of 0.05. The detected outlier is not reflected in the reported ^{222}Rn concentration.

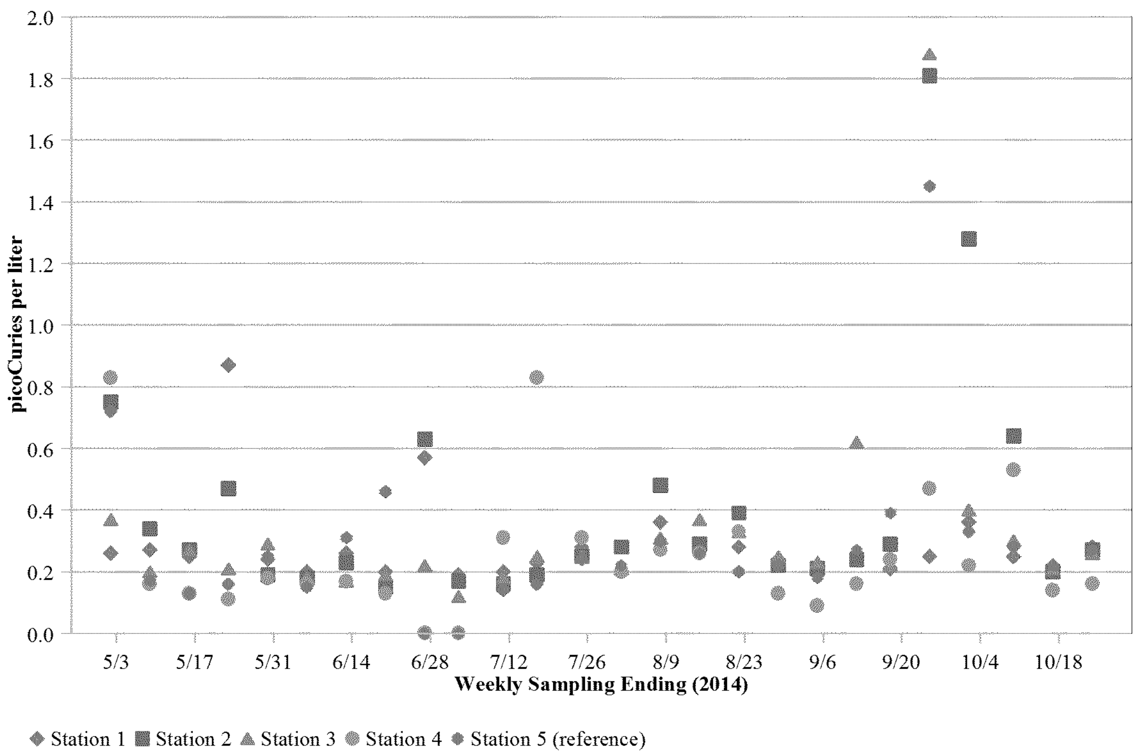
LV Indicates one (LV1) or two (LV2) of the three replicate measurements were not used in the calculation of the reported mean ^{222}Rn concentration because the measurement derived from an electret showing a reading below 200 volts.

Time Series Plot

The only discernable trend or pattern shown on the Exhibit 14 time series plot of ^{222}Rn results is that radon concentrations measured over the same week often appear related by a common component that varies in a sinusoidal pattern.

EXHIBIT 14

TIME SERIES PLOT OF RADON-222



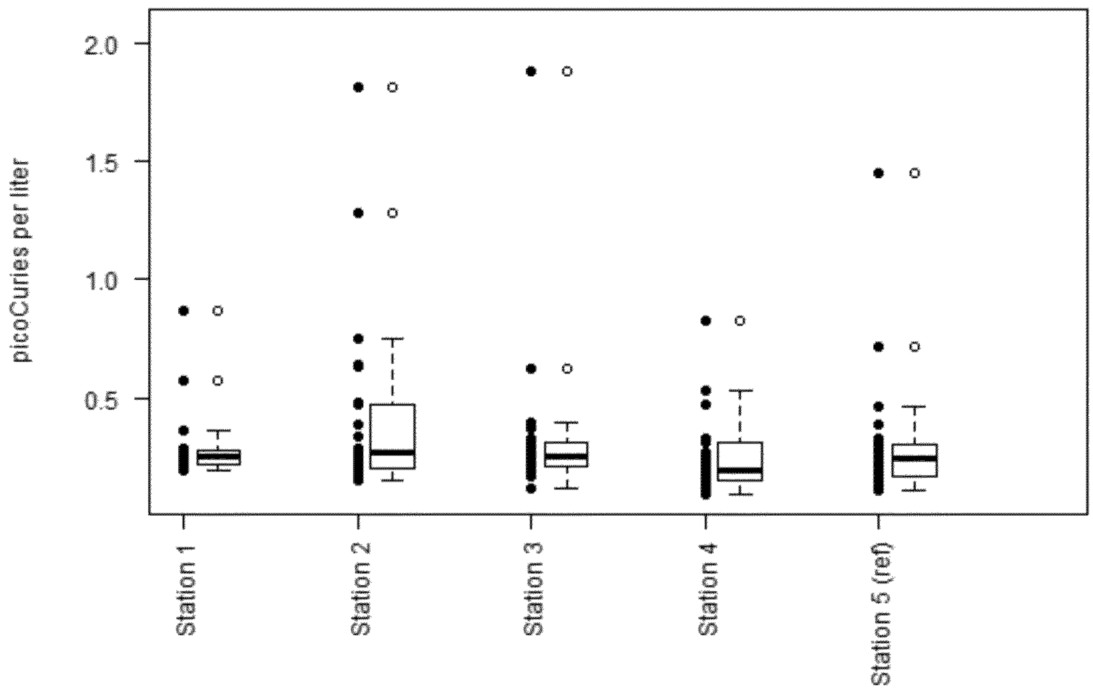
* Indicates Dixon's procedure for outlier detection could not be applied to the measurement because less than three usable replicate measurements were available.

Box Plots

Examination of the ^{222}Rn box plots in Exhibit 15 suggests that the median of ^{222}Rn concentrations is similar among the five monitoring stations. The box plots suggest upper end outlier concentrations (indicated by open circles) at each of the five stations (including the reference Station 5), about which data users should be aware; however and notably, maximum ^{222}Rn concentrations detected at each of the five stations are within an order of magnitude (the station maximums range from 0.83 to 1.88 pCi/L).

EXHIBIT 15

BOX PLOTS OF RADON ACTIVITY



4.2.4 Statistical Analyses

The Kruskal-Wallis and Friedman tests were used to evaluate the ^{222}Rn data, as these were applied to evaluate the airborne particulate radionuclide data (see Section 4.1.8). Statistical software package R was used to apply the Kruskal-Wallis and Friedman tests (see Appendix D for the input data sets, R scripts, and R output).

The Kruskal-Wallis test did not identify significant differences in mean/median characteristics of ^{222}Rn data among the five monitoring stations. The Friedman test found a tendency for some station ^{222}Rn measurements to be larger or smaller than measurements at other stations (a *p-value* of 0.0242 was reported). A post-hoc analysis regarding this test result indicated that Station 4 tended to yield smaller ^{222}Rn measurements than Stations 2 and 3, although none of the other perimeter stations (Stations 1-4)

WLLFOIA4312 - 004 - 0090633

tended to yield larger or smaller measurements than the reference station (Station 5). Table 8 summarizes the Kruskal-Wallis and Friedman test results.

TABLE 8

SUMMARY OF STATISTICAL TEST EXAMINING RADON-222 RESULTS

Statistical Test	Result of Statistical Test for Radon-222
Kruskal-Wallis[1]	No significant differences in mean/median characteristics. ($p = 0.202$)
Friedman[2]	Station 4 tended to yield smaller measurements than Stations 2 and 3; however, none of the perimeter stations (Stations 1-4) showed a tendency to yield larger or smaller measurements than the reference station (Station 5). ($p = 0.0242$)

Notes:

1 Results from the statistical software package R version 3.1.2 using the non-parametric Kruskal-Wallis test to compare the various radionuclide mean/median characteristics among the five monitoring stations. A p-value equal to or less than 0.05 suggests significant differences in mean/median characteristics among the stations. A p-value of greater than 0.05 suggests that the mean/median characteristics among the stations are comparable. See Appendix D to examine the Kruskal-Wallis test output from R.

2 Results from the statistical software package R version 3.1.2 using the non-parametric Friedman test to identify tendencies for measurements at one station to be larger or smaller than at any other station. A p-value equal to or greater than 0.05 suggests no tendency for one station to yield larger or smaller measurements than any other station. A p-value less than 0.05 suggests that one or more stations tended to yield measurements larger or smaller than other stations. See Appendix D to examine the test output from R.

4.2.5 Other Observations

Data users should be aware that about one in every three of the weekly ^{222}Rn measurements (the reported average replicate values) were qualified; these qualifications were primarily because either (1) one or more replicate measurements were deemed not usable because the final voltage was below 200 volts (those qualified “LV1” and “LV2”), or (2) Dixon’s procedure detected an outlier among three usable replicate measurements (those qualified “OH” or “OL”). Ongoing ^{222}Rn measurements are less likely to be afflicted by low voltage because corrective action has been taken to remove electrets from service earlier in their useful life. A similar percentage (around 15 percent) of replicate measurements are expected to be identified as outliers during future monitoring.

4.2.6 Recommendations for Sampling Optimization

Responses of electret ion chambers measuring radon at the five monitoring stations have been well established, and continued radon monitoring via electret ion chambers is unlikely to provide any additional information regarding baseline conditions. Therefore, Tetra Tech recommends considering baseline monitoring of radon via electret ion chambers complete, and discontinuing further monitoring.

WLLFOIA4312 - 004 - 0090635

4.3 EXPOSURE RATE MEASUREMENTS

The following sections discuss continuous external gamma exposure rate measurements taken at the five monitoring stations by use of Saphymo GammaTRACERs. Although a release of RIM via airborne particulates from WLLS is not anticipated to result in an off-site external gamma exposure rate distinguishable from background variability, acquisition of these data continues because the data possibly will be used as a reference for future monitoring campaigns that include exposure rate measurements. Moreover, sources of gamma activity not related to West Lake Landfill RIM may occasionally induce a detector response above background. Such sources may include nuclear medical materials passing by the detector (including patients receiving nuclear medicine), cosmic events (such as naturally occurring gamma-ray bursts), or precipitation to which naturally occurring airborne radionuclides adhere (as indicated in measurements presented herein and discussed in Section 4.3.2).

4.3.1 Monitoring Procedure

At each of the five monitoring stations, EPA has installed a Saphymo GammaTRACER exposure rate monitor that incorporates two Geiger-Mueller (GM) detector tubes (a high-range detector and a low-range detector). The GM tubes respond to ionization produced within the detector by gamma radiation. On an hourly basis, the GammaTRACER is programmed to report an average exposure rate reading from the previous hour-long interval. The exposure rate measurement is reported in units of microRoentgens per hour (μR/hr). The hourly measurements are transmitted wirelessly to a field command post computer and then logged by EPA Environmental Response Team's Viper data management software. Typical exposure rate readings in outdoor environments fluctuate around 10 μR/hr—this background radiation is primarily the result of cosmic and terrestrial sources of radiation (NCRP 1987).

4.3.2 Data Validation, Verification, and Usability

The exposure rate data undergo review by a member of the EPA Environmental Response Team knowledgeable of the Saphymo GammaTRACER system, and by START field staff aware of day-to-day field activities. These reviews have revealed the following information regarding the data about which users should be aware:

- At Station 1, exposure rate readings dropped by approximately 2 to 3 μR/hr on August 22, 2014. This shift in the exposure rate readings was investigated and found to have been caused by an approximately 1-foot layer of crushed limestone gravel that had been placed on the ground surface beneath the Station 1 GammaTRACER. The gravel had been placed in preparation for construction of a training structure for the Robertson Fire Protection District adjacent to firehouse

WLLFOIA4312 - 004 - 0090636

#2. The gravel had evidently caused measurable shielding of naturally occurring terrestrial radiation. The lower exposure rate readings continued until September 30, 2014, when the Station 1 GammaTRACER had to be moved to make way for the construction (the GammaTRACER was moved approximately 370 feet to the north-northeast closer to the firehouse #2 building). As evident in the plot of exposure rate readings for Station 1 (see Appendix E, Exhibit E-1), exposure rate readings increased 2 to 3 μR/hr after movement of the GammaTRACER to the new location.

- At Station 5, the wireless data transmission from the Station 5 GammaTRACER to the Saphymo receiver at the field office was initially unreliable, and some May 2014 measurements from Station 5 were intermittently lost. The unreliable data connection had been remedied by May 28, 2014.

- Plots of the GammaTRACER data revealed numerous temporary spikes in the exposure rate readings at each of the stations that occurred simultaneously at the five stations. Plotting the GammaTRACER data against precipitation events revealed a strong correlation (see Exhibit 16), indicating that the temporary spikes in exposure rate readings likely had resulted from "precipitation scavenging" (or washout) of airborne radionuclides. In this process, radionuclides (primarily radon daughter products) suspended as aerosols in the atmosphere coalesce with precipitation and are transported with the falling precipitation to the ground surface. These precipitation-scavenged radionuclides can then cause an increase in exposure rates measured in air near the ground surface (Paatero and Hatakka 1999).

Overall, the Saphymo GammaTRACER measurements are usable for the intended purpose of providing pre-construction baseline exposure rate data.

4.3.3 GammaTRACER Monitoring Data and Evaluation

Exhibit 16 shows a time series plot of GammaTRACER data acquired at the five stations from May 1 to December 9, 2014. Also on this plot, precipitation events are indicated by vertical bands. These events were identified by use of data obtained from the National Oceanic and Atmospheric Administration (NOAA) Quality Controlled Local Climatological Data (QCLCD) dataset (NOAA 2014)—specifically precipitation data acquired at the Lambert-St. Louis International Airport Station 13994, approximately 2 miles east of WLLS. A vertical band indicates a recorded hourly precipitation of 0.01 inch or more (events of only trace precipitation are not represented on Exhibit 16). Thicker bands indicate a precipitation event persisting over multiple hours. Time series plots of individual station data are in Appendix E.

EXHIBIT 16

TIME SERIES PLOT OF EXPOSURE RATE BY SAPHYMO GAMMATRACERS

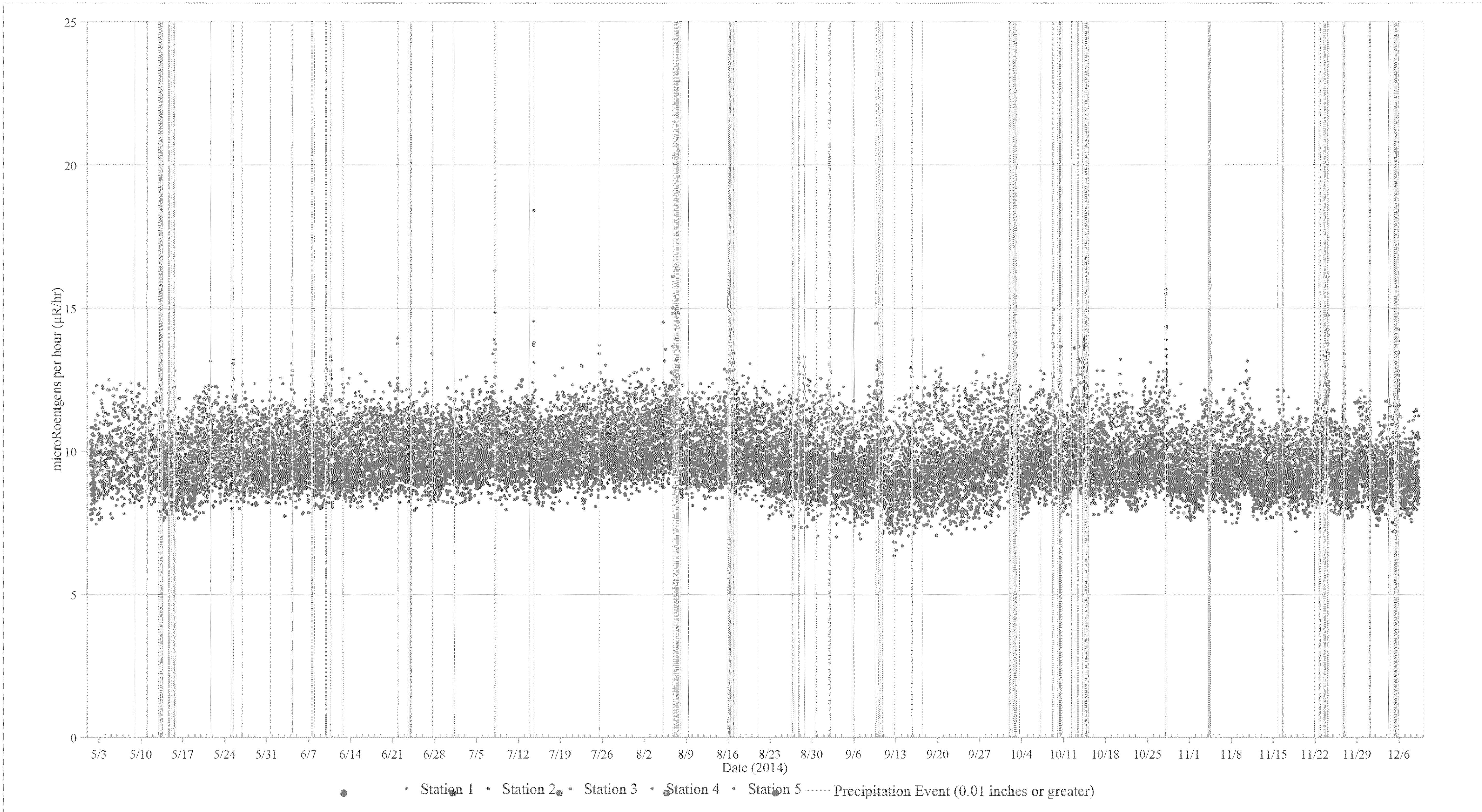


Exhibit 16 illustrates the following characteristics of the GammaTRACER data:

- Exposure rates are around 10 μR/hr—a typical exposure rate within outdoor environments (NCRP 1987)—with rates at some stations tending to be slightly higher or lower than 10 μR/hr (an expected outcome due to variations in local geology and surface conditions).

- At Station 1, exposure rate readings were noticeably lower between August 22 and September 30, 2014. As discussed in Section 4.3.2, this was the time period when crushed limestone gravel was beneath the detector (related to a nearby construction project). Exposure rate readings increased when the detector was moved to a new location to make way for construction.

- Numerous temporary spikes in the exposure rate readings strongly correspond to precipitation events. As discussed in Section 4.3.2, these occurrences likely resulted from precipitation scavenging of naturally occurring airborne radionuclides (likely radon daughter products) that caused a temporary increase in near ground-level exposure rates. Notably, all measurements exceeding 15 μR/hr appear to be associated with a precipitation event.

Overall, the gamma rate measurements appear typical for an outdoor environment.

4.3.4 Statistical Analysis

Statistical analysis to compare the mean/median characteristics among stations was not conducted because differences in the mean/median characteristics among the five stations are already evident on plots of the data (e.g., Stations 1, 2, 4, and 5 tend to have lower exposure rate measurements than Station 3). These differences are anticipated because localized differences in geology and ground surface conditions measurably affect exposure rates (e.g., placement of crushed limestone gravel beneath the Station 1 GammaTRACER detector noticeably lowered the exposure rate).

4.3.5 Recommendations for Sampling Optimization

Typical external gamma exposure rates at the five monitoring stations have been well established via monitoring by Saphymo GammaTRACER detectors since April 2014. Continued monitoring is unlikely to provide additional information regarding ambient baseline exposure rates at the five monitoring stations. Even so, monitoring with Saphymo GammaTRACERs is a largely passive operation requiring only occasional maintenance, and additional data could be obtained relatively inexpensively if desired.

4.4 ENVIRONMENTAL DOSIMETRY

Landauer, Inc. InLight optically stimulated luminescent dosimeters (OSLs) are deployed at each station to passively measure external exposure, supplementing the exposure rate measurements obtained from the Saphymo GammaTRACERs (see Section 4.3). The InLight OSLs, deployed for approximately 30 days,

WLLFOIA4312 - 004 - 0090639

provide long-term dose measurements. The InLight OSLs have a nominal minimum detectable dose of 0.1 millirem (mrem) (detecting x-ray and gamma photons with energies exceeding 15 kiloelectron-volts [keV]), and measurements are reported as an ambient dose equivalent. (Although the OSLs are deployed primarily to measure external gamma activity, the OSLs are also sensitive to beta radiation with energies exceeding 500 keV at a minimum detectable dose of 20 mrem.)

Consistent with discussion regarding the Saphymo GammaTRACER exposure rate measurements (Section 4.3), a release of RIM via airborne particulates from WLLS is not anticipated to induce an off-site external exposure that would be measureable by use of OSLs; however, the data are acquired for possible use as a reference for future monitoring campaigns that include dosimeter measurements.

4.4.1 Monitoring Procedure

Landauer, Inc. InLight OSLs are deployed at each station for continuous periods of approximately 30 days. Three OSLs are deployed per station to provide replicate measurements. When the 30-day deployment period ends, the OSLs are retrieved and shipped to the dosimeter provider for analysis.

4.4.2 Data Validation, Verification, and Usability

Review of the OSL data and field observations have revealed the following information regarding the data about which users should be aware:

- After reception of the first two rounds of OSL readings, it was suspected that elevated gamma activity from nearby masonry walls may have been contributing to OSL dose readings at some stations. This was confirmed in June 2014, when EPA and START, using a Ludlum microR, detected higher dose readings near the masonry walls at Stations 2, 3, and 4 near where the OSLs had been deployed (it is not uncommon for buildings constructed of stone or bricks to have higher natural radiation levels than buildings made of other materials such as wood [Nuclear Regulatory Commission [NRC] 2011]). Based on this information, the OSLs were re-positioned away from masonry walls (the OSLs at each station were re-positioned next to that station's GammaTRACER detector). The OSLs at Stations 1, 2, 3, and 5 were re-positioned on July 1, 2014. The OSLs at Station 4 were re-positioned on October 31, 2014.

- The dosimeter provider reports a gross dose in units of mrem for each OSL badge. The gross dose includes the dose received during the 30-day deployment, but also includes ambient dose received during the pre- and post-deployment periods because the element in the OSL is continuously exposed to ambient gamma radiation (pre-deployment time being the duration beginning when the badge is prepared by the provider and ending when the badge is deployed by the user; post-deployment being the duration beginning when the badge is retrieved by the user and ending when the badge is read by the provider). Thus, for a badge deployed 30 days, a significant portion of the gross dose reported is likely to be from doses received during pre- and post-deployment periods. Because of this, net dose values—calculated by determining differences in gross dose measurements among OSL badges—may be more useful depending on intended use of the data.

Overall, the OSL environmental dosimetry measurements are usable for measuring relative differences in long-term dose rates among the stations; however, data users should be aware that, as stated above, the OSL badges receive doses during pre- and post-deployment periods (e.g., dose received during shipment), resulting in dose readings that vary among the measurements during a particular deployment. Moreover, data users should be aware that a release of RIM via airborne particulates from WLLS is not anticipated to induce an off-site external exposure that would be measureable by use of OSLs.

4.4.3 Environmental Dosimeter Results and Evaluation

Table 9 lists the monthly OSL environmental dosimeter results for May through October 2014.

TABLE 9

ENVIRONMENTAL DOSIMETER RESULTS – GROSS DOSE

Deployment Period (2014)	Days Deployed	Station 1	Station 2	Station 3	Station 4	Station 5 (background)
April 29 – May 30	31	9.8	12.9	9.9	10.9	9.2
May 30 – July 1	32	15.0	17.4	15.3	15.9	13.9
July 1 – August 2	31	11.8	10.9	11.5	12.4	10.9
August 2 – September 2	32	10.8	10.8	10.9	11.9	10.6
September 2 – October 3	31	8.8	10.0	10.2	11.4	10.1
October 3 – October 31	28	11.9	10.9	11.4	12.5	11.5
October 31 – December 2	32	11.0	10.6	11.0	11.0	11.0

Notes:

All units in millirem (mrem)

Typical outdoor environmental dosimetry readings range from 5 to 15 mrem per month (see NCRP 1987, Table 5.4); however, as previously described, OSL dosimeter results include contributions to dose received during pre- and post-deployment periods.

Exhibit 17 shows the Station 1 through 4 OSL environmental dosimetry results net of the Station 5 (the reference station) OSL result. Relative differences between OSL results were notably greater before the OSLs were moved away from masonry building walls (on July 1 for Stations 1, 2, 3, and 5, and October 31 for Station 4). Also shown on Exhibit 17 is the difference between the minimum and maximum result (or span) for each deployment period. These values can be compared to the span between the reported

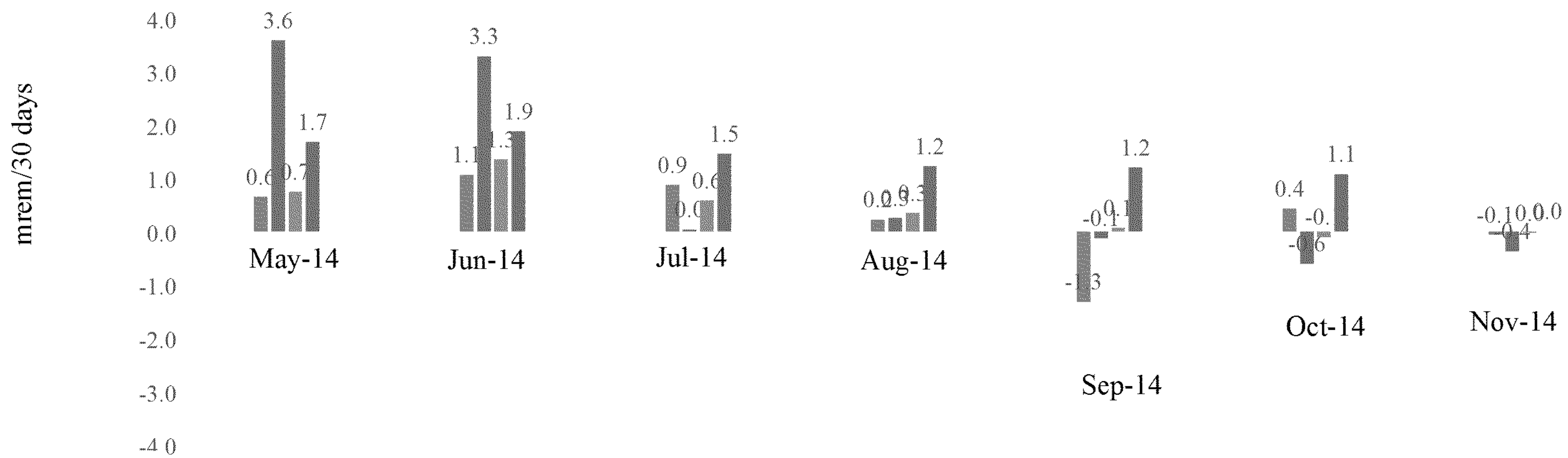
5th and 95th percentile values of the terrestrial component of the outdoor gamma-ray effective dose in the conterminous 48 states derived from airborne radiation measurements by the National Uranium Resource Evaluation (NURE) programs of 3.3 mrem/month (NCRP 2009).

EXHIBIT 17

ENVIRONMENTAL DOSIMETRY RATES BY OSL DOSIMETERS

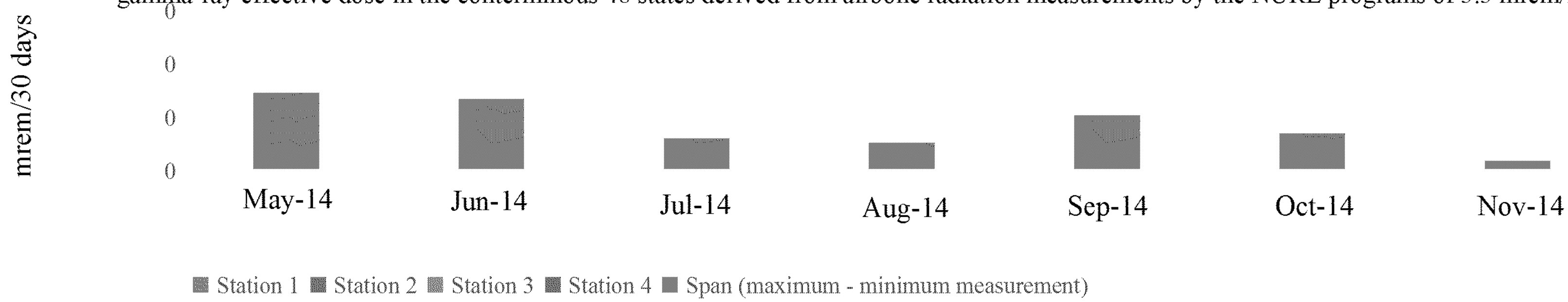
WLLFOIA4312 - 004 - 0090643

Environmental Dosimetry Rates Net of Background (Station 5)



Span of Environmental Dosimetry Dose Rates Among Stations 1-5

These span values can be compared to the span between the 5th and 95th percentile values of the terrestrial component of the outdoor gamma-ray effective dose in the conterminous 48 states derived from airbone radiation measurements by the NURE programs of 3.3 mrem/month.



WLLFOIA4312 - 004 - 0090644

Overall, the OSL dosimetry data appear normal for outdoor ambient measurements, considering the likely contributions to the dose readings from masonry building walls that occurred before the OSLs were re-positioned away from building walls.

4.4.4 Statistical Analysis

Statistical analysis to compare the mean/median characteristics among stations was not conducted because differences in the mean/median characteristics among the five stations is anticipated (as with the GammaTRACER exposure rate data)—localized differences in geology and ground surface conditions measurably affect exposure rates.

4.4.5 Recommendations for Sampling Optimization

Because external gamma exposure rates at the five monitoring stations have been well established via the monitoring by Saphymo GammaTRACER (the OSLs had been deployed primarily to provide a passive and redundant means of measuring exposure rates), continued monitoring is unlikely to provide additional information regarding baseline exposure rates at the five monitoring stations. Furthermore, usefulness of the monthly OSL data appears limited (because of the contributions to dose measurement during pre- and post-deployment periods). Therefore, Tetra Tech recommends considering the baseline monitoring by OSLs complete, and discontinuing further deployments.

WLLFOIA4312 - 004 - 0090645

5.0 SUMMARY OF OBSERVATIONS AND RECOMMENDATIONS

The following summarizes interim observations and recommendations for sampling optimization regarding radiological data acquired from approximately April to September-December 2014 at off-site monitoring stations.

5.1 SUMMARY OF OBSERVATIONS

The following are observations regarding the radiological parameters evaluated:

Radionuclides on Airborne Particulates

To determine airborne concentrations of radionuclides transported via airborne particulates, airborne particulates are being collected onto glass fiber filter media by use of high-volume air samplers. Air sampling occurs continuously, and air filter samples are collected every 7 days and submitted for laboratory analysis for gross alpha, gross beta, gamma-emitting radionuclides, isotopic uranium, isotopic thorium, and total alpha-emitting radium. The air filter results evaluated were gross alpha/beta, ^{238}U, ^{230}Th, and total alpha-emitting radium (including ^{226}Ra). Examination of box plots indicated similarity of medians and distributions of these parameters among the five monitoring stations. The box plots did reveal some suggested outliers about which data users should be aware, but the outliers were generally within an order of magnitude of the maximum concentrations detected among the other stations (the exception was total alpha-emitting radium, nearly 90 percent of the results for which were non-detect, and the maximum detected concentrations ranged from 3.66E-04 to 4.40E-03 pCi/m^3).

Two statistics tests—the Kruskal-Wallis and Friedman tests—were used to test for differences in gross alpha/beta, ^{238}U, ^{230}Th, and total alpha-emitting radium (including ^{226}Ra) concentrations among the five monitoring stations. The Kruskal-Wallis test did not identify significant differences in the mean/median characteristics among the five monitoring stations based on the data examined (gross alpha/beta, ^{238}U, ^{230}Th, and total alpha-emitting radium), and the Friedman test found no tendency for one station to yield larger or smaller measurements than any other station.

A comparison of specific alpha-emitting radionuclide results (^{238}U, ^{230}Th, and total alpha-emitting radium results) to their corresponding gross alpha results occurred to determine if the data conformed to expectation that alpha-emitting radionuclide results would be a component of (and thus less than) gross alpha results. This evaluation revealed numerous instances of nonconformity of the data to this expectation. Notably, the maximum detected ^{238}U, ^{230}Th, and total alpha-emitting radium concentrations did not conform to corresponding gross alpha concentrations. Data users should be aware of this characteristic of the data.

Radon

^{222}Rn has been identified as a radiological parameter of interest because it is a decay product of ^{226}Ra, a radionuclide of concern at WLLS. ^{222}Rn is also generated by decay of ^{226}Ra naturally occurring in soil and rock, and a significant portion of this ^{222}Rn is naturally released from the ground into the atmosphere because, as a noble gas, radon becomes unbound to soil and rock. Average weekly ^{222}Rn concentrations are measured at the five off-monitoring stations by use of electret ion chamber radon detectors (RadElec E-PERM®).

Examination of the radon box plots appears to show similar median radon concentrations among the five monitoring stations (although statistical testing suggested that Station 4 tends to yield smaller radon measurements than the other stations). The box plots suggest upper end outlier concentrations (indicated by open circles) at each of the five stations (including the reference Station 5) about which data users should be aware; however and notably, maximum detected radon concentrations among the five stations are within an order of magnitude (the station maximums range from 0.83 to 1.88 pCi/L).

Data users should be aware that about one in every three of the weekly radon measurements was qualified; these qualifications were primarily because either (1) one or more replicate measurements was deemed not usable because the final voltage reading was not within the manufacturer's recommended range for a reliable measurement, or (2) Dixon's statistical procedure detected an outlier among three usable replicate measurements. Ongoing ^{222}Rn measurements are less likely to be afflicted by low voltage because corrective action has been taken to remove electrets from service earlier in their useful life. A similar percentage (around 15 percent) of replicate measurements are expected to be identified as outliers during future monitoring.

Exposure Rate Measurements

Hourly exposure rate measurements are obtained by use of Saphymo GammaTRACER exposure rate monitors installed at each of the five off-site monitoring stations. Although a release of RIM via airborne particulates from the WLLS is not anticipated to induce an off-site external gamma exposure rate that would be distinguishable from background variability, the data are acquired for possible use as a reference for future monitoring campaigns that include exposure rate measurements. Review of the GammaTRACER data revealed that exposure rates at the five monitoring stations fluctuated around 10 μR/hr—a typical exposure rate for outdoor environments (NCRP 1987)—with readings at some stations tending to be slightly higher or lower than 10 μR/hr (expected due to variations in local geology and surface conditions). Numerous temporary spikes in the exposure rate readings corresponded to precipitation events, indicating likely precipitation scavenging (or washout) of airborne radionuclides (a process whereby radionuclides—primarily radon daughter products—suspended as aerosols in the atmosphere coalesce with precipitation and are transported with the falling precipitation to the ground surface). Overall, the gamma rate measurements appear typical for an outdoor environment.

Environmental Dosimetry

Month-long environmental dosimetry measurements are obtained at the off-site monitoring stations by use of Landauer, Inc. InLight OSLs to supplement exposure rate measurements obtained by use of Saphymo GammaTRACERs. The OSL dosimetry data appear normal for outdoor ambient measurements.

5.2 RECOMMENDATIONS

The following are Tetra Tech's recommendations for sampling optimization:

Radionuclides on Airborne Particulates

Baseline airborne concentrations of radionuclide parameters of interest at the five monitoring stations have been well established via air particulate sampling since May 2014. Continued air particulate sampling is unlikely to provide additional information regarding ambient baseline conditions. However, if continued sampling is desired, Tetra Tech suggests reducing the routine analytical parameters to gross alpha and gross beta (and analyzing for specific radionuclides on a per sample basis if a pre-determined gross alpha or gross beta threshold is exceeded).

Radon

Responses of electret ion chambers measuring radon at the five monitoring stations have been well established, and continued radon monitoring via electret ion chambers is unlikely to provide any additional information regarding baseline conditions. Therefore, Tetra Tech recommends considering baseline monitoring of radon via electret ion chambers complete, and discontinuing further monitoring.

Exposure Rate Measurements

Typical external gamma exposure rates at the five monitoring stations have been well established via monitoring by Saphymo GammaTRACER detectors since April 2014. Continued monitoring is unlikely to provide additional information regarding ambient baseline exposure rates at the five monitoring stations. Even so, monitoring with Saphymo GammaTRACERs is a largely passive operation requiring only occasional maintenance, and additional data could be obtained relatively inexpensively if desired.

Environmental Dosimetry

WLLFOIA4312 - 004 - 0090648

Because external gamma exposure rates at the five monitoring stations have been well established via the monitoring by Saphymo GammaTRACER (the OSLs had been deployed primarily to provide a passive and redundant means of measuring exposure rates), continued monitoring is unlikely to provide much additional information regarding baseline exposure rates at the five monitoring stations. Therefore, Tetra Tech recommends considering the baseline monitoring by OSLs complete, and discontinuing further deployments.

WLLFOIA4312 - 004 - 0090649

6.0 REFERENCES

National Council on Radiation Protection and Measurements. (NCRP). 1987. *Exposure of the Population in the United States and Canada from Natural Background Radiation.* NCRP Report No. 94.

NCRP. 2009. *Ionizing Radiation Exposure of the Population of the United States.* NCRP Report No. 160.

National Oceanic and Atmospheric Administration (NOAA). 2014. National Climatic Data Center Quality Controlled Local Climatological Data (QCLCD). Available online at: http://cdo.ncdc.noaa.gov/qclcd/QCLCD. Last accessed December 23.

Paatero, J. and J. Hatakka. 1999. *Wet Deposition Efficiency of Short-Lived Radon-222 Progeny in Central Finland.*

Tetra Tech, Inc. (Tetra Tech). 2014a. Quality Assurance Project Plan for Baseline Off-Site Air Monitoring and Sampling, West Lake Landfill Site, Bridgeton, Missouri. May 27.

Tetra Tech. 2014b. Data Deliverable Package 02, West Lake Landfill Site, Bridgeton, Missouri. September 8, 2014.

Tetra Tech. 2014c. Data Deliverable Package 03, West Lake Landfill Site, Bridgeton, Missouri. October 7, 2014.

Tetra Tech. 2014d. Data Deliverable Package 04, West Lake Landfill Site, Bridgeton, Missouri. October 29, 2014.

Tetra Tech. 2014e. Data Deliverable Package 05, West Lake Landfill Site, Bridgeton, Missouri. November 10, 2014.

Tetra Tech. 2014f. Data Deliverable Package 06, West Lake Landfill Site, Bridgeton, Missouri. December 16, 2014.

U.S. Environmental Protection Agency (EPA). 2004. *Multi-Agency Radiological Laboratory Analytical Protocols Manual.* EPA 402-B-04-001A. July.

EPA. 2008. *Contract Laboratory Program National Functional Guidelines for Superfund Organic Methods Data Review.* EPA 540-R-08-01. June.

EPA. 2012. *A Citizen's Guide to Radon*. EPA 402-K-12-002. May. Available online at: http://www.epa.gov/radon/pubs/citguide.html

EPA. 2012. *A Citizen's Guide to Radon*. EPA 402-K-12-002. May. Available online at: http://www.epa.gov/radon/pubs/citguide.html

EPA. 2014. Administrative Settlement Agreement and Order on A Consent For Removal Action – Preconstruction Work. EPA Docket No. CERCLA-07-2014-0002. April 20.

U.S. Nuclear Regulatory Commission (NRC). 2011. Office of Public Affairs Fact Sheet: Biological Effects of Radiation. October. Available online at: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation.pdf

APPENDIX A

FIGURES

APPENDIX B

TABULATED AIR MONITORING RESULTS

APPENDIX C

CALCULATIONS SUPPORTING RADON MEASUREMENTS

APPENDIX D

STATISTICAL ANALYSES

APPENDIX E

SAPHYMO GAMMATRACER PLOTS